A FIRST COURSE IN HEAT ENGINES

FORMERLY PUBLISHED UNDER THE TITLE "FIRST STAGE HEAT ENGINES"

BY

J. W. HAYWARD, M.Sc., A.M.I.Mech.E.

FORMERLY ASSISTANT PROFESSOR OF MECHANICAL ENGINEERING, McGILL UNIVERSITY, MONTREAL

Second Edition

London: W. B. CLIVE

University Tutorial Press Ld.

High St., New Oxford St., W.C.

1922

PREFACE.

THIS work has been designed as a first course on Heat Engines for students in Technical Classes.

The large number of simple diagrams inserted will, it is hoped, assist the reader in forming clear mental pictures, which can readily be remembered, in connection with every portion of the text.

The exercises given have been carefully selected from practice. In working them the student will, besides impressing upon himself the rules they illustrate, acquire that knowledge of the relation between the quantities with which he has to deal, so essential to a young engineer. The answers need not be worked out to more than three significant figures, as this (namely 1 in 1000) is the limit of accuracy of any apparatus that would be used in making the observations quoted.

In addition to mentioning the usual lecture-room and laboratory demonstrations of the rules given, several simple experiments, which can be carried out with home-made apparatus, have been suggested for the sake of those students who have to rely, more or less, upon their own resources.

The new chapters on Internal Combustion Engines, which differentiate this work from its predecessor *First Stage Steam*, are the work of Mr. Ewart S. Andrews, B.Sc. Eng. (Lond.), Lecturer at the Goldsmiths' College (University of London). In connection with these new chapters our thanks are due to the firms who kindly supplied information and illustrations.

NOTE TO SECOND EDITION.

In the preparation of the Second Edition of this book, the text has been revised and two small additions have been made dealing with Two-Stroke Engines and High Speed Indicators respectively.

CONTENTS.

INTRODUCTION.

A. MENSURATION.

To understand the problems dealt with in the body of this book, it is necessary to have a thorough knowledge of the following rules of mensuration. They are collected here for convenience, and stated as briefly as possible. Only those which are directly useful in simple steam-engine calculations are given; and to assist the memory, their connection with one another is roughly indicated.

1. Area of a rectangle (Fig. 1) or of a parallelogram (Fig. 2).

$$\text{Area} = B\,H$$

The triangle $a\,b\,c$ (Fig. 2) can be removed and placed in the position $a'\,b'\,c'$, where it makes up with the remainder of the parallelogram a rectangle of area $B\,H$.

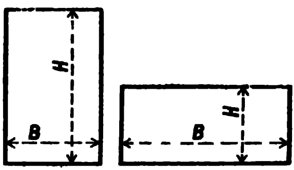


FIG. 1.

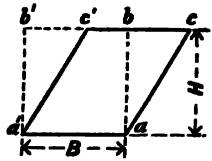


FIG. 2.

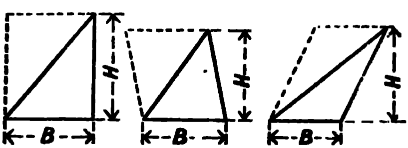


FIG. 3.

2. Area of a triangle (Fig. 3).

$$\text{Area} = \tfrac{1}{2}\,B\,H$$

As indicated by the dotted lines, a triangle is half the area of a parallelogram on the same base B and of the same height H.

3. Area of a Trapezoid (Fig. 4).

NOTE.—A trapezoid is a four-sided figure with two parallel and two non-parallel sides.

$$\text{Area} = \tfrac{1}{2}(H_1 + H_2)B = H_m B,$$

where H_m is the height measured mid-way between the parallel sides.

If we imagine the triangles abc and def turned round into the positions $ab'c'$ and $de'f'$, it will be seen that the trapezoid is equal in area to a rectangle of area $H_m B$.

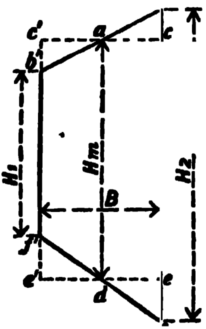


FIG. 4.

4. Approximate area of any irregular figure such as Fig. 5.

Divide the area up into any even number of parts by equi-distant parallel lines of lengths H_1, H_2, H_3, etc., at a distance b apart, and let B be the total breadth of the figure.

Replace the original contour by a series of straight lines, as shown. These, together with the dividing lines, form a set of trapezoids whose combined area is very nearly the same as that of the irregular figure.

$$\begin{aligned}\therefore \text{Area} &= 2bH_1 + 2bH_3 + 2bH_5 + 2bH_7 + 2bH_9 \\ &= 2b(H_1 + H_3 + H_5 + H_7 + H_9) \\ &= \frac{B}{5}(H_1 + H_3 + H_5 + H_7 + H_9) \\ &= B\,\frac{H_1 + H_3 + H_5 + H_7 + H_9}{5}\end{aligned}$$

Since it is only necessary to measure B and H_1, H_3, H_5, H_7, H_9, no other lines need be drawn.

Hence the following rule :—

To find the area of any irregular figure, divide it by vertical lines into an odd number of parts, making the two end divisions half the breadth of the rest.

The sum of the lengths of the verticals, divided by their number, and multiplied by the total breadth, gives the area of the figure.

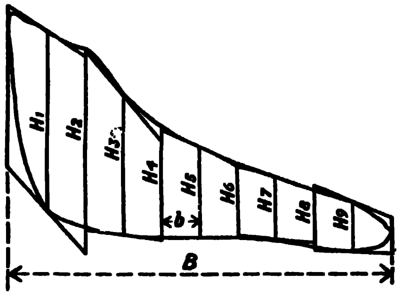


FIG. 5.

Ten verticals, or *ordinates*, are usually sufficient, dividing the area into eleven parts.

5. **The circumference of a circle (Fig. 6).**

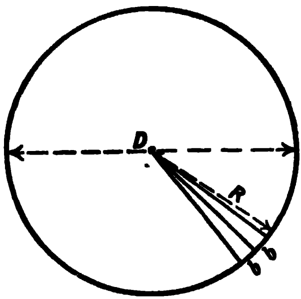


FIG. 6.

$$\text{Circumference} = 3{\cdot}1416\,D$$

$$(= 3{\cdot}14\,D \text{ or } 3\tfrac{1}{7}\,D \text{ approximately.})$$

This rule may be verified by measuring with a tape the circumference and diameter of a circular wheel.

6. The area of circle (Fig. 6)

$$= \frac{3 \cdot 14}{4} D^2$$
$$= \cdot 785\, D^2$$

The area may be divided into a very large number of sectors, as shown, of height R ($= \frac{1}{2} D$) and base b, say. If these sectors are taken narrow enough, the difference between them and triangles of area $\frac{1}{2} R b = \frac{1}{4} D b$ will be inappreciable; therefore the area of each sector may be taken as $\frac{1}{4} D b$.

$$\therefore \text{Area of the whole circle} = \tfrac{1}{4} D\, (b + b + b + b + + \text{etc.}$$
$$= \tfrac{1}{4} D \text{ (circumference of circle)}$$
$$= \tfrac{1}{4} D \times 3 \cdot 14\, D$$
$$= \frac{3 \cdot 14}{4} D^2$$

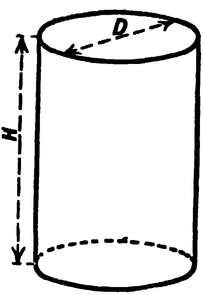


Fig. 7.

7. Area of curved surface of a cylinder (Fig. 7).

= Circumference of cylinder × height of cylinder

$= 3 \cdot 14\, D H.$

8. Volume of a cylinder (Fig. 7).

= Area of cross section of cylinder × height of cylinder

$= \cdot 785\, D^2 H.$

The Planimeter.

For measuring areas bounded by irregular lines, an instrument called a planimeter may be used. One form of this is shown diagrammatically in Fig. 8. It consists of two arms X and Y hinged at Z. Y rotates about a fixed centre P (a needle-point stuck into the paper). The arm X carries a tracing-point T and also a wheel W, whose axis is in the line joining T and Z. If the instrument is laid on a flat surface, and the tracing-point T is moved completely round the boundary of any closed figure, the wheel W will turn through an angle proportional to its area.

There is a scale on the rim of the wheel by which this angle can be measured, and it is so graduated that the corresponding number of square inches can be read off directly.

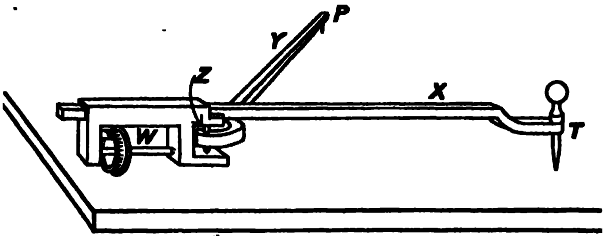


FIG. 8.—Amsler's Planimeter.

Ex. 1.—Show by experiment that the area of the triangle is half that of the rectangle in Fig. 9.

Draw the figures to scale on stout cardboard, cut them out and weigh them.

In an actual case the weights were found to be as follows—

Triangle = $52\frac{1}{4}$ grains.
Rectangle = $103\frac{1}{2}$ „
$\therefore \frac{1}{2}$ Rectangle = $51\frac{3}{4}$ „

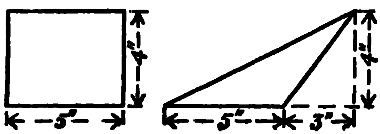


FIG. 9.

The difference of $\frac{1}{2}$ grain would be accounted for by the roughness of the experiment.

Ex. 2.—Show that the area of a circle 6 inches in diameter is $\frac{3.14}{4} \times 6^2 = 28.3$ square inches nearly.

Cut out a circle 6 inches in diameter from the same cardboard as was used in example 1 and weigh it.

In an actual case weight of circle was found to be 145 grains.

Now the rectangle, measuring $5 \times 4 = 20$ square inches in area, weighed $103\frac{1}{2}$ grains.

$$\therefore \text{ weight of 1 square inch of cardboard } = \frac{103\frac{1}{2}}{20} = 5.18 \text{ grains.}$$

$$\therefore \text{ the area of the circle } = \frac{146}{5.18} = 28.2 \text{ square inches.}$$

Ex. 3.—A bucket weighs 4 lbs. empty, and 37 lbs. 4 oz. when full of water; find its capacity in cubic feet.
(1 cubic foot of water weighs 62·3 lbs.)

$$\text{Weight of water} = 37 \text{ lbs. } 4 \text{ oz.} - 4 \text{ lbs.}$$
$$= 33 \text{ lbs. } 4 \text{ oz.}$$
$$= 33{\cdot}25 \text{ lbs.}$$

$$\text{Volume of water} = \frac{\text{weight of water}}{\text{weight of 1 cubic foot of water}}$$

$$\therefore \text{capacity of bucket} = \frac{33{\cdot}25}{62{\cdot}3} = {\cdot}534 \text{ cubic foot.}$$

Ex. 4.—Find the weight of a cast-iron cylinder, 3 feet in diameter, 5 feet high and 1 inch thick.
(1 cubic inch of iron weighs ·27 lb.)

$$\text{Area of cylinder} = 3{\cdot}14 \times 3 \times 5 \text{ square feet.}$$
$$= 3{\cdot}14 \times 3 \times 12 \times 5 \times 12 \text{ square inches.}$$
$$\therefore \text{volume of metal} = 3{\cdot}14 \times 3 \times 12 \times 5 \times 12 \times 1 \text{ cubic inches.}$$
$$\therefore \text{weight of metal} = 3{\cdot}14 \times 3 \times 12 \times 5 \times 12 \times 1 \times {\cdot}27 \text{ pounds}$$
$$= 1{,}830 \text{ pounds.}$$

EXAMPLES A.

NOTE.—Take the weight of 1 cubic inch of iron to be ·27 lb.

1. A sheet of iron 10 feet by 5 feet is divided by a line drawn from the centre of a long side to one of the opposite corners. Find the area of each division.

2. If the iron in question 1 is $\frac{1}{8}$ inch thick, find the weight of each division.

3. What length of bar iron is required to make a hoop 3 feet in diameter?

4. Find the length of string required to wrap 100 times round a pipe 4 inches in diameter.

5. A bicycle wheel is 28 inches in diameter. Find how many revolutions it makes in travelling a mile (1760 yards).

6. A locomotive driving-wheel is 6 feet in diameter, find how many revolutions it makes in travelling a mile.

7. Find how many revolutions the above wheel makes in one minute when the engine is running at 45 miles an hour.

8. An engine fly-wheel, 10 feet diameter, makes 100 revolutions per minute. How many feet will any point on its circumference move per second?

9. The large wheels of a locomotive (6 feet diameter) make 240 revolutions per minute. Find how many revolutions the small wheels (4 feet diameter) make.

10. Find the area of the cross section of a cylinder 6 inches in diameter.

11. The flat end of a boiler is 7 feet in diameter. Find its area in square inches.

12. If the above boiler is working at a pressure of 100 lbs. per square inch, find the total force on either end in tons.

13. A piston is 20 inches in diameter, and the steam pressure on it is 30 lbs. per square inch. Find the total force on it in pounds.

14. The total steam pressure on a piston 12 inches in diameter is 2000 lbs. Find the pressure per square inch.

15. A cast-iron pipe is 4 inches internal diameter, 5½ inches external diameter. Find the area of metal in its cross section.

16. Find the area of a semi-circle 5 inches diameter by taking 10 ordinates at right angles to the diameter, and also by the formula for a circle.

17. Find in square feet the external area of a pipe 3 inches in external diameter and 10 feet long.

18. The furnace gases in a locomotive boiler pass through 180 tubes 2 inches in external diameter and 12 feet long. Find the heating surface due to these (*i. e.* their total area).

19. Find the total external area of a boiler 30 feet long and 8 feet in diameter.

20. Find the weight of 10 feet of an iron pipe of 4 inches mean diameter and ½ inch thick.

21. Find in cubic feet the volume of steam in a cylinder 26 inches long and 18 inches in diameter.

22. Find the weight of a cast-iron piston 12 inches in diameter and 2 inches thick.

23. The rim of a fly-wheel, 10 feet in diameter, is 12 inches broad and 6 inches thick. Find its weight in tons.

24. Water is flowing through a pipe 4½ inches diameter at the rate of 100 feet per minute. Find the number of cubic feet discharged per hour.

25. The cylinder of a small engine is 3 inches in diameter and 6 inches long. It is filled with steam twice in each revolution. Find the number of cubic feet of steam used in 100 revolutions.

B. THE USES OF SQUARED PAPER.

(*a*) *Reduction of experimental results.*—Many questions arise in practical engineering which are best dealt with graphically. For example, a series of experiments may have been made to determine how one quantity, say the quantity of steam generated in a boiler per hour, varies with another, say the quantity of coal burnt in the furnace.

If, for each experiment in such a series, a point is marked down on a sheet of paper, so that its distance from a certain line is proportional to one of the quantities, and its distance from a second line, at right angles to the first, is proportional to the other quantity, we obtain, by joining these points, a diagrammatical representation of the relation sought, from which much can be learnt.

For this purpose paper ruled into squares, one-tenth of an inch across, can now be purchased cheaply. Every fifth or tenth line is made darker than the rest, to simplify counting up the divisions. Its use will be well illustrated by the following examples.

Ex. 1.—A railway engine draws trains of various lengths at a uniform speed of 30 miles per hour over a certain piece of line. The weights of these trains and the corresponding quantities of coal burnt per hour in the locomotive are given below.

Weight of train. Tons.	Coal burnt per hour Pounds.
800	900
600	730
300	480
Engine alone	225

Express these results in a diagram, and find how the coal burnt per ton load varies with the load.

In this case our two variables are the *weight of the train* and the weight of the *fuel consumed*. Take measurements along two lines at right angles (OX and OY, Fig. 10) to represent these.

Let each division along OX represent 20 tons load, and each division along OY represent 20 lbs. of coal.

By measuring 40 divisions along OX, and 45 upwards, a point is found corresponding to the fuel burnt at the maximum load. By measuring 30 divisions along OX, and 36½ upwards, a second point is found corresponding to the fuel burnt for a 600 tons load. The points for 300 tons and no load are found similarly. Now draw an even line as nearly as possible through these points.

This line represents the probable coal consumption for any load

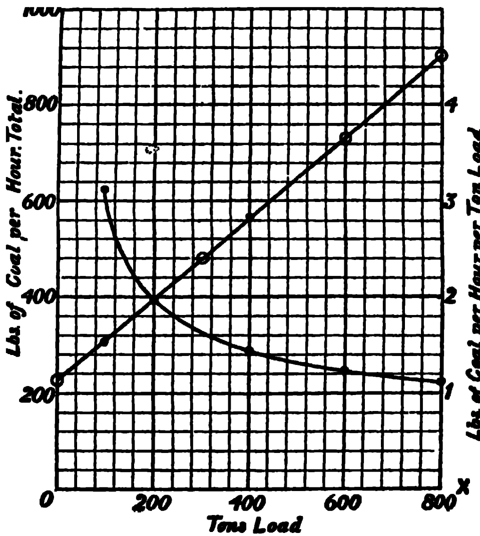


FIG. 10.—Variation of coal consumption in a locomotive with load drawn.

between those given. Thus, it shows that 390 lbs. of fuel per hour would be burnt when drawing a train of 200 tons.

NOTE.—As it is impossible to make absolutely accurate experiments, the points representing the results will not always lie on a continuous line. In such a case a "mean line" must be drawn, passing as nearly as possible through all the points, but without humps or breaks in it. This artifice tends to correct accidental errors in individual experiments; but it does not tend to correct any error running through the whole series.

The second part of the example is solved by dividing the heights of a series of points on the line drawn, by their distances from OY,

measured on the scales marked, and plotting the quotients to the same scale of loads, and a new vertical scale on which 10 divisions represent one pound of coal.

Load in tons.	Coal burnt per hour. Pounds.	Pounds of coal burnt per hour per ton load.
100	310	3·10
200	390	1·95
400	570	1·42
600	730	1·22
800	900	1·12

NOTE.—This example is founded on actual results, so that we learn from it, first, that within the range of loads given, the more the engine does the more economically it works, and secondly, that this increase in economy though rapid at first is very gradual near the maximum load.

For convenience of reference it is usual to call distances measured horizontally (*i. e.* along *OX*) **abscissæ** and distances measured vertically **ordinates.**

(*b*) *The application of known laws to solve special problems.*—Graphical methods are just as useful when it is desired to apply a law determined by previous experiment to a special case. The next example will illustrate this.

Ex. 2.—An electric light station when making its maximum output of 600 kilowatts, uses 1,920 lbs. of coal per hour. When its load factor is 30 per cent. (that is, when its output is $600 \times 30 \div 100$), it uses 1026 lbs. of coal per hour. What will be the probable consumption of coal per hour when the load factor is 12 per cent.? (S. and A. 1900.)

Here the known law is, that the variation of coal consumption with output (or load) can be represented, approximately, by a straight line.

Mark off some convenient horizontal scale, say 200 kilowatts = 1″ and a vertical scale, say 500 lbs. = 1″ (see Fig. 11).

Plot a point *A* corresponding to 600 kilowatts and 1,920 lbs. of coal, and a second point *B* corresponding to $600 \times 30 \div 100$, *i. e.* 180 kilowatts, and 1,026 lbs. of coal.

Draw a straight line through *A* and *B* and find upon this a third point *C*, whose abscissa is $600 \times 12 \div 100$ or 72 kilowatts.

The ordinate of *C* gives the required coal consumption, namely 795 lbs.

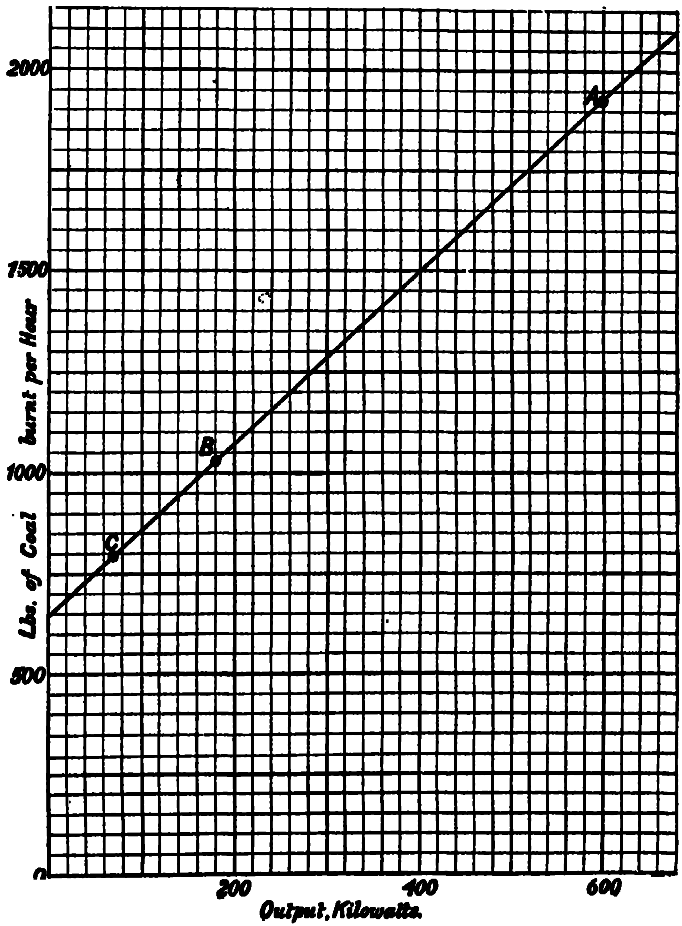

2000
1500
1000
500
0
A
B
C
Lbs. of Coal burnt per Hour
200
400
600
Output, Kilowatts.

FIG. 11.

(*c*) *The conversion and correction of scales.*—A third use of squared paper is for converting measurements on one scale into corresponding measurements on another. Thus, if we desire to convert a series of weights stated in kilogrammes into pounds we may proceed as follows:—

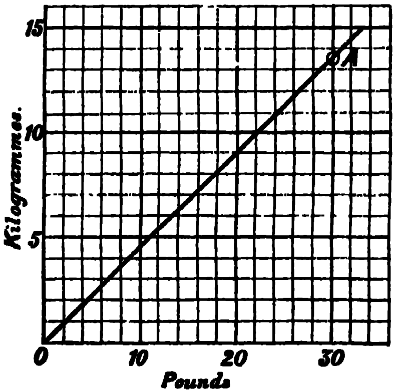


Fig. 12.—Graphical method of converting kilogrammes into pounds.

Take each vertical division (see Fig. 12) to represent one kilogramme, and each horizontal division to represent 2 lbs. Now 1 lb. is equivalent to ·453 of a kilogramme, or 30 lbs. are equivalent to 13·59 kilogrammes. Plot a point *A* opposite the latter pair of readings; then any point on a straight line drawn through *A*, and the zero, gives corresponding values in the two measures. Thus 10 kilogrammes are shown to be equal to 22·05 lbs., and so on.

This method may also be used to find the correct reading on gauges or thermometers when these are known to be graduated incorrectly and the error has been determined at certain points. Scale divisions are marked as abscissæ and true values (lbs. per square inch or degrees) as ordinates. In this way a series of points are plotted showing the correct values for certain of the scale readings; and the curve drawn through these points is the "correction curve" for the instrument. The corrected value of any other reading is given by the ordinate to this curve, measured from the corresponding point on the horizontal scale.

EXAMPLES B.

1. A cargo steamer burns 8 tons of coal a day, when unloaded, and 32 tons of coal a day, when steaming at the same speed, fully loaded. Find graphically the probable coal consumption when half loaded.

2. A series of experiments made to determine the fuel consumption of a motor car gave the following results:

Speed, miles per hour.	Pints of Petrol consumed per hour.
6	2·1
8	3·4
10	5·0
12	7·0
15	10·6

Plot these on squared paper and draw a curve through them.

3. A bicycle costs £12, and 30 shillings a year for repairs. Find graphically how much will be expended on it in 5 years.

4. If the owner of the above bicycle rides 1000 miles a year on it, thereby saving £5 in railway fares, find how soon it will pay him.

5. A pump requires 340 lbs. of steam to raise 1,200 gallons of water per hour, and 610 lbs. of steam to raise 2,700 gallons per hour. Find the probable weight of steam required to raise 3,000 gallons per hour.

6. A diving-bell containing 400 cubic feet of air at a pressure of 15 lbs. per square inch, is lowered into water to a depth of 20 feet. The pressure in it rises ·43 lb. per square inch for each foot it descends. Draw a curve showing how the volume of the air varies.

NOTE.—The volume of the air will vary inversely as the pressure, see Chapter II, page 32.

7. Draw a figure for converting gallons into cubic feet (1 gallon = ·1605 cubic foot) that will read by gallons up to 100 gallons.

8. Draw a figure for converting centimetres into inches (1 inch = 2·54 centimetres), reading by millimetres up to 10 centimetres.

(1 millimetre = $\frac{1}{10}$ centimetre.)

9. A pressure gauge has been tested and its error determined at the following points:

Pressure per square inch.	Gauge readin
0	0
20	24
40	46
60	62

Draw a correction curve for it and use this to determine the gauge reading for a pressure of 30 lbs. per square inch.

CHAPTER I.

THE STEAM-ENGINE IN ITS SIMPLEST FORM.

1. Construction of a Steam-engine.—The beginner must acquaint himself thoroughly with the names, the uses, and the connection with one another, of the principal parts of a steam-engine, before attempting to study the theory of its action.

He can gain this knowledge best from a comparatively small engine, such as that shown in Figs. 13, 14 and 15, in the construction of which simplicity has been aimed at rather than economy in steam consumption, the chief consideration in designing those of large power. Fig. 13 is a side view of an engine suitable for driving the machinery in a small factory. Fig. 14 is a plan of the same engine, with the top part of the cylinder *C*, the valve-chest *V.C* and the valve *V* removed down to the line *XX* (Fig. 13).

Fig. 15 is a view of the opposite side to that shown in Fig. 13. *In this the valve-chest V.C and the shaft S are supposed to be cut away down to the line YY (Fig. 14) and* part of the slide-valve *V* is omitted to show the steam-ports. The drain-cocks also are omitted.

In each case the parts are marked with the initial letters of their names, to assist the student in learning these. He should carefully compare their arrangement in this engine with that in others, those for instance at any workshop to which he has access, on board a steamer, or upon the railway.

The action of the steam can best be understood by tracing its path from the steam-pipe *S.P* to the exhaust-pipe *E.P*.

S.V is the stop-valve placed near the engine, within easy reach of the engineer. It is controlled by a hand-wheel (on the far side in Fig. 13).

Next to the stop-valve, which is regulated by hand, comes the throttle-valve, controlled automatically by the governor *G*. The mechanism of the governor is so contrived that, if the speed of the engine increases (owing to a decrease in the work to be done) the throttle-valve is partially closed, and *vice versâ*. It acts in the following manner. The valve has a long spindle protruding from the casing, and passing freely through the centre of a bevelled wheel, driven by the engine. Fixed to this wheel, and also to the top of the spindle, are four flat steel springs with weights mounted upon them. These weights, as they revolve, tend to fly out, till, when the speed becomes too great, they bend the springs, thus shortening them, and depressing the spindle, so as to close the valve.

Since the throttle-valve and governor will take up a position such that just sufficient steam is admitted to do the work required, it is evident that the average speed of the engine will slightly increase as the load decreases and less steam is wanted, and *vice versâ*.

Having passed the throttle-valve, the steam now enters the slide-valve chest *V.C*, and its further progress is regulated by the slide-valve *V*, which moves backwards and forwards over three openings called ports. The two outermost of these, the steam-ports, lead to the ends of the cylinder *C*, while the central one, the exhaust-port, opens into the exhaust-pipe *E.P*.

The cylinder *C* has it ends closed by steam-tight covers, the front one being part of the frame *F*, and the back one being readily removable for examining the interior of the engine.

Within the cylinder is the piston *P*. Fixed firmly to the latter is the piston-rod *P.R*. This extends through the front cylinder cover to the cross-head *C.H*, which is guided by the cross-head guides *C.H.G*, so that it can only move in a straight line.

The connection between the piston and the shaft *S*, is completed by the crank-disc *C.D*, the crank-pin *C.P*, and

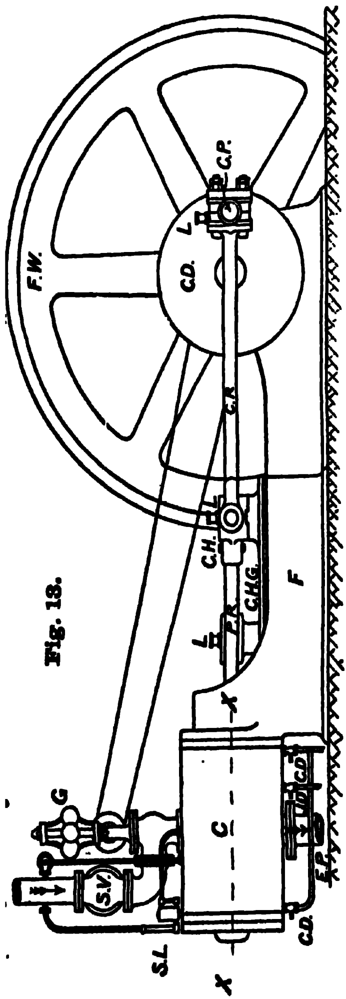

F.W.
C.D.
L
C.P.
C.R.
C.H.
C.H.G.
P.R.
L
F
X
G
S.V.
C
C.D.
E.P.
S.L.
X

Fig. 13.

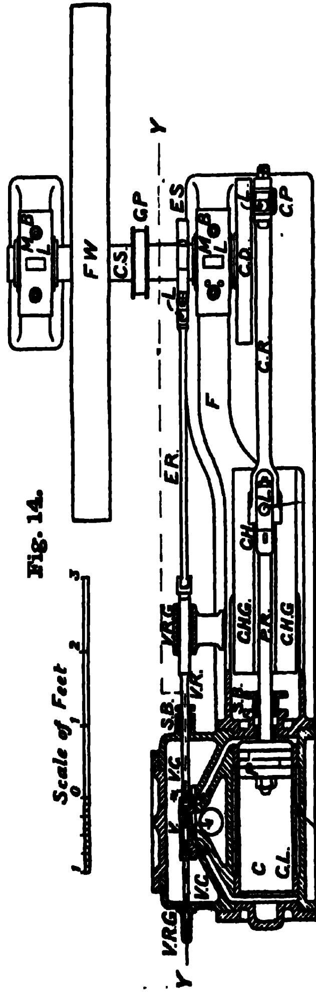
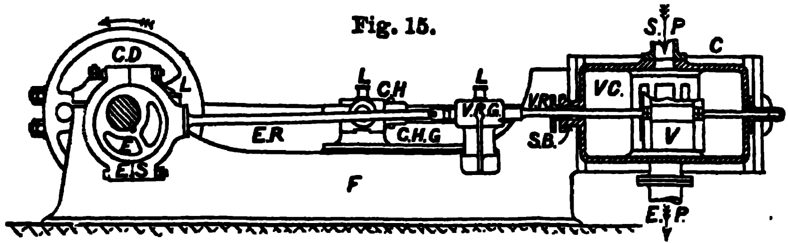

M.B.
L
FW
C.S.
GP
ES
L
Y
M.B.
L
C.D.
C.P.
C.R.
F
E.R.
C.H.
V.R.G.
C.H.G.
P.R.
C.H.G.
V.R.
S.B.
S.B.
V.C.
V.C.
C
C.L.
S.J.
V.R.G.
Y
Scale of Feet
1 0 1 2 3

Fig. 14.

Fig. 15.



FIGURES 13, 14, AND 15.

Three views of a horizontal non-condensing engine: diameter of cylinder, 10 inches; stroke of piston, 20 inches.

Reference Table.

S.P.	Steam-pipe.	P.R.	Piston-rod.	V.C.	Slide-valve chest.
S.V.	Stop-valve.	S.B.	Stuffing-box, or gland.	V.R.	Valve-rod.
E.P.	Exhaust steam-pipe.	C.H.	Cross-head.	V.R.G.	Valve-rod guide.
G.	Governor.	C.H.G.	Cross-head guides.	E.	Eccentric.
G.P.	Governor pulley.	C.R.	Connecting-rod.	E.S.	Eccentric-strap.
C.	Cylinder.	C.D.	Crank-disc.	E.R.	Eccentric-rod.
C.L	Cylinder liner.	C.P.	Crank-pin.	F.W.	Fly-wheel.
C.D.	Cylinder drain-cocks.	C.S.	Crank-shaft.	S.L.	Sight-feed cylinder lubricator.
S.J.	Steam-jacket.	F.	Engine frame.		
J.D.	Steam-jacket drain-cock.	M.B.	Main bearings.	L.	Other lubricators.
P.	Piston.	V.	Slide-valve.		

C

We must now see how the steam causes the piston to move, and why this reciprocating motion makes the shaft revolve.

This engine is arranged to run in the direction indicated by the arrow. The piston is shown at the end of its stroke, and the slide-valve in its corresponding position is just commencing to allow steam to enter the front steam-port, while it has made a connection, through its hollow underside, between the back end of the cylinder and the exhaust-port, and thus through the exhaust-pipe to the air. There is, therefore, the full pressure of the live steam on the front side of the piston, and only a very small pressure opposing it on the other side, due to the resistance of the escaping steam. This difference of pressure will cause a tension in the piston-rod and connecting-rod, and a force on the crank-pin. In all positions but two (at the ends of the stroke) any force applied like this will turn the shaft, in the same way that the pressure of one's feet on the pedals tends to turn the cranks of a bicycle except when they are at the top or bottom. And further, just as the weight and velocity of the rider and his machine carry the latter past these dead points, so the heavy fly-wheel of an engine prevents it stopping.

In *starting* an engine the dead points are a serious difficulty, to overcome which various methods are adopted. Locomotives have two cranks, set at right angles, and marine engines three or more, while large mill engines have some device for barring them round into a position where the steam will take effect.

As soon as the connecting-rod becomes inclined, the steam pressure causes further motion, and the slide-valve will move to the right (Fig. 15), as well as the piston, thus opening the front port fully, and keeping the back port in connection with the exhaust-pipe.

After about $\frac{1}{8}$ of a revolution, the valve will have reached the end of its travel and will begin to retrace its path, so that after $\frac{1}{4}$ of a revolution (or when the piston has moved $\frac{3}{8}$ of the length of the cylinder) it will be in the same position as it was to start with; that is to say, it will just be closing the front port. After this, for the rest of the piston stroke, the

steam supply to the cylinder is "cut off," and that which has already been admitted expands and exerts a decreasing pressure on the piston. Just before the end of the stroke the slide-valve will have moved so far to the right that the back steam-port is closed and the front one is put in connection with the exhaust-pipe. Finally after half a revolution the back steam-port will be opening to steam, the front port will be open to the exhaust, and the slide-valve will be moving to the left, ready to perform the same cycle of operations for the out stroke of the piston as for the in.

If the reader copies the slide-valve and piston on slips of tracing paper, so that he can move them into their various corresponding positions, it will assist him in following this description.

The cylinder is lagged outside with some non-conducting material, held in place by a sheet-iron covering. It consists of a cast-iron shell into which a liner is fitted. Between shell and liner is a space filled with steam by the branch pipe shown in Fig. 13. The water condensed is drained away through the cock *J.D.* The object of this "*steam-jacket*" is to prevent condensation of the working steam.

Some water will be sure to find its way into the cylinder at starting, and this may choke the steam-ports and even fracture the cylinder cover, by being driven violently against it. Such accidents are avoided by opening the drain-cocks *C.D*, till they discharge nothing but steam.

A similar cock (not shown) is also fitted for draining the valve-chest.

Although the piston *P*, when new, might be made to fit the cylinder so well that little or no steam could leak past it, it would very soon wear loose. Instead of attempting such useless accuracy of workmanship, therefore, two broad, thin, split piston-rings are employed. These are held in place laterally by a flange at the front and a removable "*junk ring*" at the back. They are elastic and are pressed outwards by an internal, coiled spring, so that they adapt themselves automatically to any change of diameter in the cylinder.

Leakage from round the piston-rod and valve-rod is prevented by enlarging the outer part of the holes, through

which these enter the cylinder and valve-chest, and filling the vacant space with some form of compressible packing (hemp, asbestos, or soft metal). A loose collar, or *gland*, is screwed down on top of the latter, which then makes a close-fitting joint without causing excessive friction. This arrangement is called a *stuffing-box* (see *S.B*, Figs. 14 and 15).

Since the cross-head is subject to oblique forces from the connecting-rod, it has to be supported by guides *C.H.G.* These take the form of a planed surface on the frame, upon which the foot of the cross-head bears, and cover-plates with grooved sides. The engine must run in the direction indicated, so that the greatest pressure is always downwards, against the frame, and not upwards against the cover-plates.

The crank-shaft *C.S* is supported by two main bearings *M.B.* These each consist of a pair of brass blocks, lined with white metal, and supported in a cast-iron frame with a removable cover.

The large, or crank, end of the connecting-rod *C.R* also consists of brass blocks bolted together, while its small forked end carries a pin passing through a brass bush in the cross-head.

The slide-valve has its motion imparted to it by an eccentric *E.* This may be described as a crank in which the pin is made so much larger than the shaft that it embraces it. The centre of the eccentric is set about 120 degrees in advance of the crank to make the slide-valve take up its proper position, relative to the piston. The eccentric-strap *E.S* corresponds to a connecting-rod end. It carries the eccentric-rod *E.R* which is hinged to the valve-rod *V.R*, the weight of both being borne by the valve-rod guide *V.R.G.*

All the working parts are lubricated from oil-boxes, one of which is shown to a larger scale in Fig. 16. A supply of oil is stored in a reservoir, whence it is siphoned by a cotton wick into a pipe leading to the bearing surfaces. The wick is removed when the engine is stopped.

A special device, called a "sight-feed lubricator," has to be resorted to in the case of the piston and slide-valve (see *S.L*, Fig. 13). Water is allowed to condense in the long cooling pipe to the left, and this presses on the oil in the central

reservoir, and forces it drop by drop through the gauge-glass and the right-hand pipe into the steam-chest, close to the ports.

The whole structure rests on a solid block of concrete, 3 feet 6 inches thick, and is held in place by 6 holding-down bolts, 1 inch in diameter, passing right through the foundation.

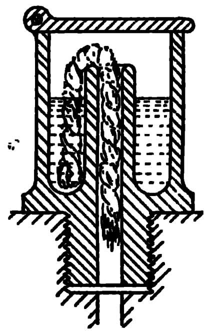


FIG. 16.—Siphon Lubricator.

2. Work.—A more detailed description of many of the parts mentioned above will be found in the succeeding chapters. For the present, the attention must be turned from the construction of the steam-engine to its uses. These include pumping water, lifting minerals from mines, drawing trains, propelling steam-ships, and driving the shafting and machinery in factories, or the dynamos in electric power and lighting stations.

In every one of the above cases, it will be seen that the duty of the engine is to move something through space against a resistance, and this is called *doing work.* The water and minerals are raised against their own weight. The trains are drawn against the friction of their axles. The steam-ships are propelled against the resistance of wind and water. The factory engine turns the rim of its fly-wheel against the pull of the driving-belt upon it, and in the dynamo, the outer surface of the armature is moved against powerful magnetic forces.

Doing work, then, consists in causing motion against a resistance. In measuring work, therefore, both the distance moved, and the resistance overcome, must be taken into account. Thus we get the following important definition :—

WORK.—*When a body is moved through any distance, against a resistance, work is done upon it. The amount of work done is equal to the product of the resistance and the distance moved against it.*

If a body be moved obliquely to the direction of a resistance, this motion may be split up into two parts, one in the direction of the resistance, and the other at right angles to it. Only the first of these is involved in calculating the work done.

Work is also done upon a body when its velocity is increased. This case will be considered later.

It is usual in this country to measure the distance in feet, and the resistance in pounds, so that the work is stated in *foot pounds*.

Ex. 1.—A man raises a stone weighing 2 pounds, 3 feet high. How much work does he do?

2 feet × 3 pounds = 6 foot pounds of work.

Ex. 2.—One pumping engine raises 40,000 pounds of water 50 feet, while another is raising 7,000 pounds 300 feet. Which does the greater amount of work?

Work done by first pump = 40,000 × 50 = 2,000,000 foot pounds.
Work done by second pump = 7,000 × 300 = 2,100,000 foot pounds.

Ex. 3.—A mill engine fly-wheel is 10 feet in diameter. The difference in the pull of the two sides of the belt upon it is 400 pounds. Find the work the engine does per revolution.

The distance moved by any point on the rim of the fly-wheel in one revolution = circumference of wheel = 3·14 × 10 = 31·4 feet.

This distance is moved through against a pull of 400 pounds.
∴ Work done per revolution = 31·4 × 400 = 12,560 foot pounds.

Ex. 4.—A horse tows a barge at the rate of 4 miles an hour. How much work does he do per minute, if the tension in the rope is 90 pounds?

The distance moved per minute = $\frac{4 \times 1{,}760 \times 3}{60}$ = 352 feet.

∴ Work done per minute = 352 × 90 = 31,680 foot pounds.

3. Power.—There is another factor which must now be

taken into consideration, and that is the *time* in which work is done.

One engine is said to be more powerful than another, if it can get through the same amount of work in less time.

Thus a steam pump which raises 10,000 pounds of water a minute, through 100 feet, is said to be twice as powerful as one that can only raise 5,000 pounds the same height, in the same time.

Now engines were first introduced to replace horses, and a very good horse can do 33,000 foot pounds of work in a minute. Hence an engine which could do this was called a "one-horse-power" engine. One which could do 66,000 foot pounds of work a minute was called a "two-horse-power" engine, and so on.

This rule, which is stated in a concise form below, is still used.

HORSE-POWER.—*To find the horse-power of an engine, divide the number of foot pounds of work it does per minute by* 33,000.

Ex. 5.—A winding engine raises a weight of 2 tons, 300 feet in 2 minutes. Find its horse-power.

$$\text{Total work done} = 2 \times 2{,}240 \times 300 \text{ foot pounds.}$$

$$\therefore \text{Work done per minute} = \frac{2 \times 2{,}240 \times 300}{2} \text{ foot pounds.}$$

$$\therefore \text{Horse-power} = \frac{2 \times 2{,}240 \times 300}{2 \times 33{,}000} = 20{\cdot}4 \text{ nearly.}$$

When an engine is employed to drive a dynamo, the work it does can be determined very simply by measuring the electrical current and voltage generated.

The current (measured in amperes) represents the rate at which electricity is generated, and the voltage (measured in volts) represents its pressure. These quantities are read directly on instruments called ammeters and voltmeters. They are reduced to horse-power by the following rule—

$$\frac{\text{amperes} \times \text{volts}}{746} = \text{horse-power.}$$

In the case of pumping engines also, the work done can be calculated from the amount of water delivered, and the height it is raised, but, since it is impossible to tell accurately

what the resistance of trains, of ships, or even of workshop machinery is, some other way of determining the work absorbed in driving these must be resorted to.

4. Indicated Horse-Power.—Fortunately there is an alternative method which is very simply applied.

The mean effective pressure of the steam on the piston, that is to say the average difference of pressure upon its two sides, can be measured by means of an instrument called the *indicator*, which will be described in Chapter II. Now, it is this difference of pressure which moves the piston, therefore the work done by the steam on the latter, per stroke, is equal to the mean effective pressure multiplied by the length of the stroke. This work done by the steam on the piston is the same as that which is done by the piston on the piston-rod, by the piston-rod on the connecting-rod, by the connecting-rod on the crank, by the crank on the driving-wheel, and so on; it is, in fact, the work given out by the engine, except that a small portion of it is absorbed in the friction of the glands, guides, bearings, etc., on the way.

The work done per minute on the piston, is the work done per stroke, multiplied by the number of strokes made per minute, and this quantity, expressed in foot pounds and divided by 33,000, gives the horse-power of the engine. It is called the *indicated horse-power* (written *I.H.P.*) because the indicator is employed to determine it. As has been pointed out, the horse-power, measured from the work the engine does against an outside resistance, or the *effective horse-power*, is always less than this, because some work is taken up in driving the engine itself.

An engine of 100 *I.H.P.* will require about 15 *H.P.* to drive it, so that its effective horse-power will be only 85 *H.P.*

Other engines of different powers will absorb a proportionate amount.

The fraction

$$\frac{\text{Effective horse-power}}{\text{Indicated horse-power}}$$

is called the *mechanical efficiency* of an engine.

It must be remembered that the power lost in an engine remains nearly constant however little outside work it is doing; thus the 100 *I.H.P.* engine above has a mechanical efficiency of ·85 at full load, but this falls to ·7 at half load, and ·4 at one-quarter load.

The effective horse-power is often called the brake horse-power (*B.H.P.*), as small engines are tested by applying a brake, of known resistance, to their fly-wheels before they are sold.

The calculation of the indicated horse-power of an engine is so important that we must now deduce a formula for it, which can be committed to memory.

Let p = the mean effective pressure per square inch on the piston, as determined with the indicator.

A = the area of the piston in square inches.

L = the length of the stroke in feet.

N = the number of revolutions the crank makes per minute.

The total effective pressure on the piston

$$= p\,A.$$

Since the piston makes two working strokes for each revolution of the crank, the distance it moves per minute is

$$2\,L\,N.$$

∴ The work done per minute

$$= p\,A \times 2\,L\,N$$

$$\therefore \text{horse-power} = \frac{p\,A \times 2\,L\,N}{33{,}000}$$

or, rearranging the letters in the top line

$$I.H.P. = \frac{2\,p\,L\,A\,N}{33{,}000}$$

a rule very easy to remember.

Ex. 6.—Find the indicated horse-power of the engine illustrated in Figs. 13, 14, and 15 when it is running at 110 revolutions per min., and the mean effective pressure on the piston is 30 lbs. per sq. inch.

$$I.H.P. = \frac{2\,p\,L\,A\,N}{33{,}000} = \frac{2 \times 30 \times \frac{20}{12} \times 10^2 \times {\cdot}7854 \times 110}{33{,}000}$$

$$= \frac{2 \times 30 \times 20 \times 100 \times {\cdot}7854 \times 110}{12 \times 33{,}000}$$

$$= 26{\cdot}2 \text{ nearly.}$$

Ex. 7.—The area of an engine piston is 10 square inches, and its stroke 6 inches. Find how fast it must run to develop 2 horse-power when the mean effective pressure is 33 lbs. per sq. inch.

$$I.H.P. = \frac{2\,p\,L\,A\,N}{33{,}000}$$

$$\therefore\ N = \frac{33{,}000\ I.H.P.}{2\,p\,L\,A} = \frac{33{,}000 \times 2}{2 \times 33 \times \frac{1}{2} \times 10} = 200 \text{ revs. per min.}$$

If the reader has not seen a large engine tested, he should procure a model of some kind, and measure the power it will develop. A great deal may be learnt from judicious experiments of this sort.

Fig. 17 is a photograph of a brake, fitted by the author to a small vertical engine, which works admirably.

The model is placed upon a box, on the side of which a pendulum is pivoted at *F*. To the top of the pendulum is tied a cord, which passes over the grooved pulley *P*, and carries a weight at its lower end.

The foot of the pendulum forms a pointer, moving in front of a cardboard scale graduated in the following way. Before steam was got up, a series of very small weights were hung on the cord in turn, and the positions the pointer took up were marked.

For each weight this position varied between two limits, on account of the friction of the shaft bearings, etc.; one limit was obtained by turning the wheel to the right, and letting it go, and the other by turning it to the left. A point midway between these extremes was taken as the reading on the scale, when the tension *w* in the cord equalled the weight, for at one extreme the whole friction was acting with the weight, and at the other it was acting against it. In this manner the scale was constructed to read up to $\frac{3}{4}$ of an ounce.

When the engine was running, the friction of the cord against the pulley tended to raise the weight *W*, and so reduced the tension *w* till slipping took place.

The resistance against which the pulley turned was, therefore, the difference between *W* and *w*. The former could be altered at will and the latter read on the scale.

Below are the results of an actual experiment:

TEST OF MODEL VERTICAL ENGINE.

Diameter of pulley at bottom of groove		$= \cdot 57''$
Revolutions per minute . . .		$= 320$
Large weight *W*		$= 2$ ozs.
Tension *w*		$= \frac{21}{32}$ oz.
∴ Resistance	$= \frac{43}{32}$ oz.	$= \cdot 084$ lb.
Distance moved against this resistance per revolution	$= \dfrac{3\cdot 14 \times \cdot 57}{12}$	$= \cdot 149$ foot
Ditto per minute	$= \cdot 149 \times 320$	$= 47\cdot 68$ feet
∴ Work done per minute . . .	$= 47\cdot 68 \times \cdot 084$	$= 4\cdot 01$ ft. lbs.
∴ Brake horse-power . . .	$= 4\cdot 01 \div 33{,}000$	$= \cdot 00012$

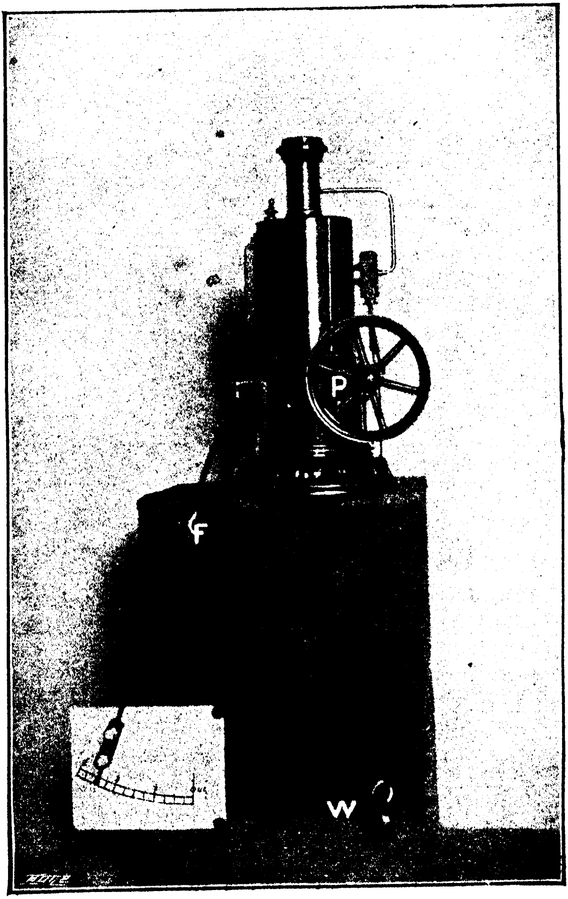


FIG. 17.—Photograph of a brake for testing a model. A similar device can be used for engines up to 5 H.P.

After reading Chapter X, this experiment should be extended, by measuring the fuel consumptions required to produce various powers.

EXAMPLES I.

1. Sketch a section through the cylinder and valve-chest of a simple engine, naming all the parts shown.

2. Sketch and describe a piston-rod stuffing-box.

3. How is the motion of the piston of an engine communicated to its crank-shaft?

4. Why are cross-head guides necessary?

5. State the uses of (1) the drain-cocks, (2) the steam-jacket, of an engine cylinder.

6. Describe briefly the action of a governor.

7. Describe, with sketches, the action of a slide-valve in admitting steam to an engine cylinder and allowing it to escape.

8. How are the slide-valve and piston lubricated?

9. How is the motion of the slide-valve produced?

10. Describe clearly, with sketches, the working of any single cylinder, direct acting, non-condensing engine with slide-valve and eccentric. (S. and A. 1897.)

11. Define *work*.

12. A locomotive and train weighing 200 tons ascend an incline of 1 in 350 for 2,000 yards. Find the work done against gravity.

(The distance actually moved against gravity is $2{,}000 \times \frac{1}{350}$ yards.)

13. Find the work a tug does, per minute, in towing a vessel at a speed of 4 knots, when the tension in the hawser is 600 lbs.

(1 knot = 6,080 feet per hour.)

14. In what units do we measure the rate at which work is done, and how are they derived?

15. Find the effective horse-power required to raise 1,000 cubic feet of water 50 feet in one hour.

(1 cubic foot of water weighs 62·3 lbs.)

16. Find the horse-power required to tow the vessel referred to in question 13.

17. A man weighing 150 lbs. climbs Ben Nevis (4,400 feet high) in $1\frac{1}{2}$ hours from sea level; at what horse-power does he work?

18. A launch engine has a cylinder 6 inches in diameter. The mean effective pressure is 40 lbs. per square inch. Find the total effective pressure on the piston and the work done per stroke of 9 inches.

19. Find the horse-power of the above engine when making 440 strokes per minute.

20. A steam-engine has a steam cylinder of 20 inches in diameter, the crank measures 18 inches from the centre of crank-shaft to centre of crank-pin, the engine runs at 85 revolutions per minute, and the mean effective pressure of steam on the piston is 28 lbs. per square inch. Find the indicated horse-power of the engine. (S. and A. 1896.)

(The stroke is twice the length of the crank.)

21. The two cylinders of a locomotive are each 17 inches in diameter, the length of each crank is 12 inches, the mean effective steam pressure is 80 lbs. per square inch, and the driving-wheel of the locomotive makes 110 revolutions per minute; under these conditions, what is the H.P. of the engine? (S. and A. 1899.)

22. A winding engine indicates 90 H.P. when it is raising a weight of 3 tons at a uniform rate of 300 feet per minute; find what fraction of this power is lost in friction.

23. An engine piston is 12 inches in diameter and its stroke is 18 inches; find the number of strokes it must make per minute for the engine to develop 20 I.H.P. when the mean effective pressure is 22 lbs. per square inch.

24. Find the mean effective pressure on an engine piston 6 inches diameter and 10 inches stroke, when 8 E.H.P. is being developed at 110 revolutions, (1) neglecting friction, and (2) assuming a mechanical efficiency of ·85.

CHAPTER II.

ACTION OF STEAM IN AN ENGINE.

5. Expansion of Steam.—To understand the action of steam in driving the piston of an engine from end to end of the cylinder, it will be simplest in the first place to consider a special case where the admission and escape of the steam are regulated by hand and not by a slide-valve as described in Chapter I.

Fig. 18 represents the cylinder of such an engine with its piston, piston-rod and gland, but, instead of two steam-ports, there are four cocks *A*, *B*, *C*, *D* in the cylinder covers. Of these, *A* and *B* admit steam from the boiler, *C* and *D* allow it to escape into the air. *G* and *G′* are pressure gauges to indicate the pressure on the left and right sides of the piston.

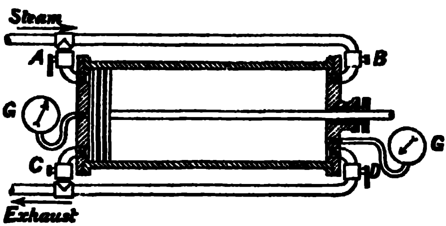


FIG. 18.—Cylinder with four separate cocks for distributing the steam.

It will make the work clearer to assume that steam is supplied from a boiler at some definite pressure, say 45 lbs. per square inch above the atmospheric pressure. Since the atmosphere exerts a pressure of about 15 lbs. per square

inch, the steam pressure is really $(45 + 15)$ lbs. above zero, or 60 lbs. per square inch absolute, as it is called.

14·7 lbs. is the true mean value of the atmospheric pressure. It varies as much as half a pound above and below this mean; thus it is often 15 lbs., so we take that figure here for simplicity.

The piston is shown at the left-hand end of the cylinder. If cocks *A* and *D* are opened, the pressure on the right of the piston will be that of the atmosphere, 15 lbs. per square inch absolute. That on the left of the piston is 60 lbs. per square inch absolute. There is, therefore, 45 lbs. more pressure on every square inch of the piston on the left-hand side than on the right.

If we take—

A = area of piston in square inches.
L = stroke of piston in feet (*i.e.* the distance it can move within the cylinder),

The total effective pressure on the piston

$$= (60 - 15)\,A = 45\,A \text{ lbs.}$$

If cocks *A* and *D* are kept open, this pressure will move the piston to the right-hand end of the cylinder. The work the steam will do in driving it there is—

Total effective pressure × length of stroke $= 45\,A\,L$ ft. lbs.

To do this work

$$\frac{A}{144}\,L \text{ cubic feet of steam}$$

have been removed from the boiler and will be discharged into the air on the return stroke.

As gauges are only made to record pressures above that of the atmosphere, *G* will read 45, and *G′* 0. Owing to this custom, it is usual to refer to pressures measured above atmospheric pressure as "*pressures by gauge*" to distinguish them from "*absolute pressures*."

Let us now see what happens if cock *A* is closed when the piston has traversed one-fourth of its stroke. In this case only $\frac{1}{4}$ as much steam will be removed from the boiler into the cylinder.*

When cock *A* is closed, there is still an excess of pressure

amounting to 45 lbs. per square inch on the left side of the piston. The latter will therefore continue moving to the right; but, instead of fresh steam from the boiler coming to occupy the space left behind it, this space has to be filled by the steam already in the cylinder. As this steam expands, its pressure falls. When the piston is at half-stroke, the gauge G will be found to read about 15, at $\frac{3}{4}$ stroke it will read about 5, and at the end of the stroke it will read 0.

We must now find a law connecting these pressures with the corresponding volumes.

Adding 15 to each of the gauge readings, we get the absolute pressures 30, 20 and 15.

Vol. of steam at	$\frac{1}{4}$	stroke	$= \frac{1}{4} A L$,	pressure	$= 60$	lbs.	absolute.
" "	$\frac{1}{2}$	"	$= \frac{1}{2} A L$,	"	$= 30$	"	"
" "	$\frac{3}{4}$	"	$= \frac{3}{4} A L$,	"	$= 20$	"	"
" "	full	"	$= A L$,	"	$= 15$	"	"

Now $\frac{1}{4} A L \times 60 = \frac{1}{2} A L \times 30 = \frac{3}{4} A L \times 20 = A L \times 15$ from which we deduce the following rule—

If P and V are the absolute pressure and volume of the steam admitted to the cylinder at the commencement of expansion, and P_1, V_1 its absolute pressure and volume at any other point on the stroke,

$$P_1 V_1 = P V.$$

The conditions under which steam expands in an engine are extremely complex, partial condensation and re-evaporation occur as well as great changes in temperature, so that no existing formula will give results in complete accordance with observation, and the above simple rule is as useful as any.

6. Boyle's Law.—When a gas like air or coal gas, which does not readily liquefy, expands or is compressed and its temperature is not allowed to change, the product of its pressure and volume does remain almost exactly constant.

Robert Boyle discovered this fact in 1662, so it is usually referred to as *Boyle's Law*. In words it may be stated thus—

BOYLE'S LAW:—*The volume of a given mass of gas varies inversely as the absolute pressure, provided the temperature is kept constant.*

This law may be proved experimentally with the simple apparatus shown in Fig. 19. This consists of two large glass tubes, one long, and the other short, mounted on each side of a scale and connected by an indiarubber pipe. The short tube is fixed, but the long one can be moved up and down. Mercury is poured into these till it stands opposite the zero mark, and then the short pipe is closed with an air-tight plug. A column of air, say 10 inches high, and at atmospheric pressure, is thus enclosed. Now the pressure of the atmosphere is measured, in the barometer, by a column of mercury about 30 inches high, so that if the long tube be raised till the mercury in it stands at a height of 30 inches above that in the short tube, the air will evidently be subject to twice the atmospheric pressure, and it will be found that it only fills 5 inches of the tube. Its volume has, therefore, been reduced by one half.

The levels of the liquid in this case are indicated by dotted lines.

Similarly, to double the volume of the gas, the pressure on it must be halved, or the long tube must be lowered till the mercury in it stands at half the barometric height, or 15 inches below that in the short tube.

The experiment must be performed slowly, for the air is heated by compression and requires time to cool down to its original temperature.

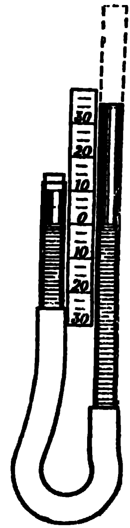


FIG. 19.—Apparatus for demonstration of Boyle's law.

7. Work done during expansion.—For the steam-engine the equation $P_1 V_1 = P V$ is best stated in another form.

Let the steam supply be cut off at a fraction r of the stroke, and let r_1 be any greater fraction—

$$\text{Then } V = A\,r\,L$$

$$\text{Let } V_1 = A\,r_1\,L$$

$$\text{Then } P_1\,A\,r_1\,L = P\,A\,r\,L$$

$$\text{Or } P_1\,r_1 = P\,r.$$

To show the use of this rule we may calculate by it the pressure at $\frac{4}{5}$ of the stroke—

$$P = 60,\ r = \tfrac{1}{4},\ r_1 = \tfrac{4}{5}$$

$$\therefore P_1\,\tfrac{4}{5} = 60 \times \tfrac{1}{4}$$

$$\therefore P_1 = 18\tfrac{3}{4} \text{ lbs. per sq. in. absolute.}$$

The reading on the gauge will be

$$18\tfrac{3}{4} - 15 = 3\tfrac{3}{4}$$

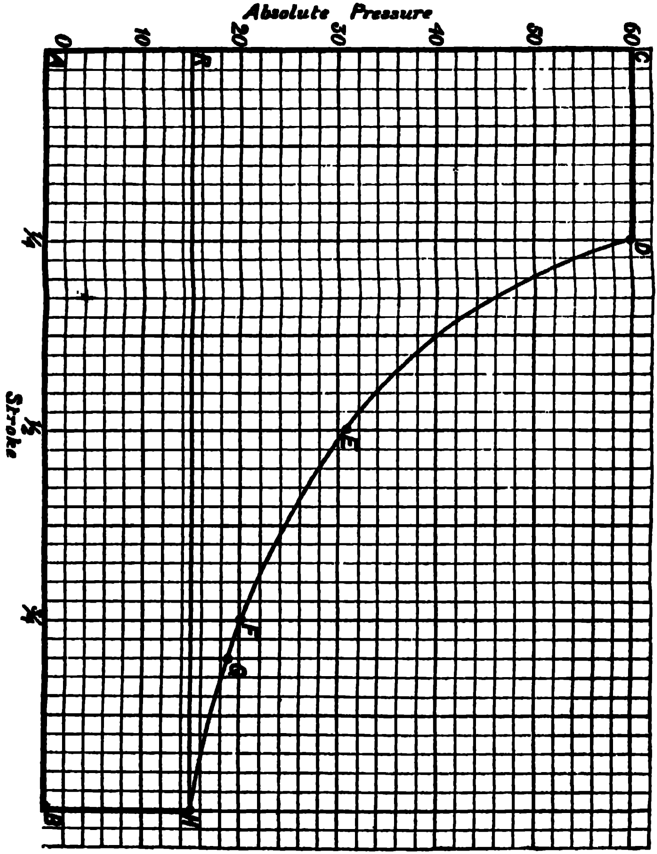


FIG. 20.

The above results may be represented graphically on a sheet of squared paper thus:—Set off a length AB, say 4 inches long (see Fig. 20), to represent the stroke L, and take each division vertically to mean, say, 2 lbs. pressure per square inch. If then we draw AC 3 inches long, it will represent the absolute pressure on the left side of the piston which remains constant for the first quarter of the stroke. To show this draw CD horizontal. Mark off by the points E, F, G, H the pressures calculated at $\frac{1}{2}$, $\frac{3}{4}$, $\frac{4}{5}$, and the end of the stroke, and draw in by hand a curve, as shown. Since the pressure falls continuously from D to H, its value at any point other than those already considered will be given approximately by the height of this curve above AB at that point. For example, the pressure at $\frac{5}{8}$ of the stroke is represented by 12 divisions, and is therefore 24 lbs. per sq. in. absolute.

The above expansion curve may be found by a purely geometrical method if the stroke and point of cut-off be known.

In Fig. 21, AB represents the stroke, K the point at which steam is cut off, and AC the absolute pressure. Complete the rectangles $ABIC$ and $AKDC$. Then D is one point on the curve and

$$AK = V$$
$$KD = P$$

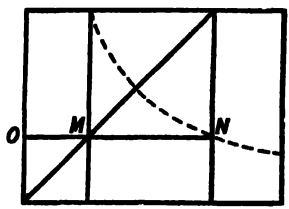


FIG. 21.

Construction.

Take any point L on DI and join it to A by a line cutting DK in M.

Draw OMN and LNQ parallel to AB and AC. Their intersection N is another point on the curve.

To prove this we must show that

$$AQ \times QN \text{ or } P_1 V_1 = AK \times KD \text{ or } PV.$$

Proof.

Triangle ACL = triangle AQL . . 1

" AOM = " AKM . . 2

" MDL = " MNL . . 3

Subtracting 2 and 3 from 1

Rectangle $OCDM$ = rectangle $KMNQ$.

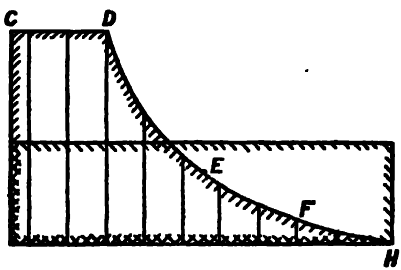
Adding rectangle $AOMK$ to each of these we have

Rectangle $ACDK$ = rectangle $AONQ$,
but area $ACDK = AK \times KD$
and area $AONQ = AQ \times QN$
$\therefore AQ \times QN = AK \times KD$.

Any number of other points may be found similarly.

The geometrical name of the curve found thus is the "*hyperbola.*"

Two ways have now been given of obtaining the absolute pressure on the left side of the piston for every point of the stroke. If a line RH is drawn (Fig. 20) $7\frac{1}{2}$ divisions above AB, it will represent the atmospheric or "back" pressure on the right side of the piston, and the distance between RH and CDH will indicate the effective pressure.



If we divide the area into a great number of very narrow strips, the mean height of each strip represents the mean effective pressure on the piston while it is moving through a distance corresponding to the breadth of the strip. But the work done on the piston is proportional to the mean pressure multiplied by the distance moved, *i. e.* it is proportional to the mean height of the strip multiplied by its breadth, or to the area of the strip.

Since, therefore, the area of each strip is proportional to

the work done on the piston while it is traversing the corresponding portion of its stroke, the total area of the diagram *RCDH* represents the total work done on the piston during the whole stroke.

This area may be found by rule 4 in the Introduction, or with a planimeter, or by adding up the number of squares included by it. If it be divided by the length of the diagram, the quotient will be the mean height of the diagram, or the height of a rectangle (shown in Fig. 22) of the same length and area. This height represents the constant pressure on the piston, acting throughout the stroke, which would be required to do the same amount of work. The latter is called the *mean effective pressure*, and is the quantity referred to in Chapter I, page 24, as being used in calculating the indicated horse-power of an engine.

As stated in the Introduction, it is sufficiently accurate to take 10 ordinates in measuring areas of this form. The rule for finding the mean effective pressure from a diagram will then read thus—

Divide the length into 11 *parts, making the two end divisions half the size of the rest, and measure the height at each of the points found. The sum of these heights, divided by* 10, *gives the mean height of the diagram, and is proportional to the mean effective pressure.*

On page 31 it was shown, that when steam was admitted during the whole stroke, the work done was 45 A L ft. lbs. Now let us see how much work can be done by admitting $\frac{1}{3}$ the quantity of steam, and allowing it to expand. The pressures represented by the 10 ordinates in Fig. 22 are 45, 45, 45, 27·9, 18·3, 12·3, 8·1, 5·0, 2·6, 0·8; their mean value is 21. Therefore the work the steam will do per stroke is

$$21\ A\ L \text{ ft. lbs.}$$

Thus, though only $\frac{1}{3}$ as much steam is used it does

$$\frac{21\ A\ L}{45\ A\ L} = \frac{21}{45}$$

or nearly half as much work. In other words we get nearly twice as much work out of each pound of steam used.

This shows plainly the economy of expansive working.

In the first case the steam escaped at a high pressure. In the second case it was made to do as much work as possible by expanding it till its pressure fell as low as the back pressure. If the back pressure could be reduced below 15 lbs. per square inch, we should either get a higher mean effective pressure, or we could use less steam, and expand it in a greater ratio, getting still more work per pound out of it. This is what is actually done in condensing engines, as will be shown in Chapter XI.

8. Effects of Clearance and Wire-drawing.—So far in this chapter a specially constructed engine has been dealt with. We must now compare this with the common form, and see what modifications the differences between the two will introduce into our results.

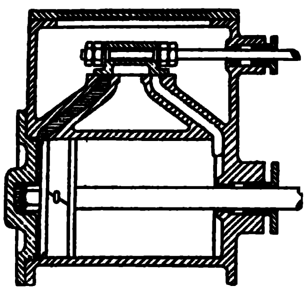


FIG. 23.—Section of engine cylinder showing clearance space.

On looking at Fig. 23, which is a section through an ordinary engine cylinder, we see that there is a considerable space between the piston, when it is at the end of its stroke, and the slide-valve. This space is called the *clearance volume*, or simply the *clearance*. It is indicated by horizontal shading in the figure. It varies from 0·08 of $A\ L$ (or the volume swept out by the piston) in large engines to 0·15 in small ones.

The clearance volume has to be filled with steam every stroke, and as this steam expands along with that in the cylinder, the pressure falls more slowly than in our special engine.

To save the waste which would occur if this space had to be filled with fresh steam every stroke, it is usual to stop the escape of steam a little before the end of the previous stroke, so that the piston may compress what remains into the clearance.

Another difference is that the slide-valve opens and closes the steam-ports slowly, compared with the rate at which the piston moves. The steam cannot at these times get through the opening fast enough to maintain the same pressure in the cylinder, as in the valve-chest. It is then said to be "*wire-drawn.*" To insure full pressure at the beginning of the stroke, the valve is made to commence admitting steam a little early, the breadth of steam-port which is uncovered at the beginning of the stroke being called the "*lead.*"

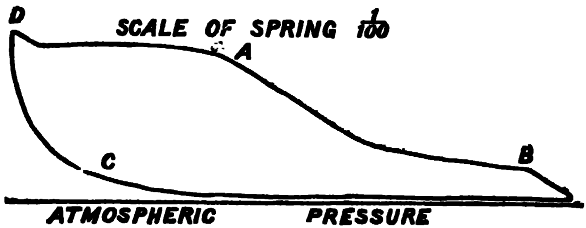


FIG. 24.—Indicator diagram.

To prevent increased back pressure at the beginning of the return stroke, steam is allowed to escape before the piston reaches the end of the cylinder.

Wire-drawing occurs also when the steam supply is cut off, and there it cannot be reduced in engines fitted with the simple slide-valve.

The effects of wire-drawing, early release, and compression, are well illustrated at *A*, *B*, and *C* in Fig. 24, which is a diagram showing the variation in pressure at one end of the cylinder of a real engine. Wire-drawing is prevented at *D* by the lead.

9. The Indicator.—The above diagram (Fig. 24) was taken with an *indicator*, an instrument which has been referred to previously, and which must now be described in detail. A Crosby indicator (one of the best on the market) is shown in Fig. 25, and the method of attaching this to a horizontal engine, in Fig. 26.

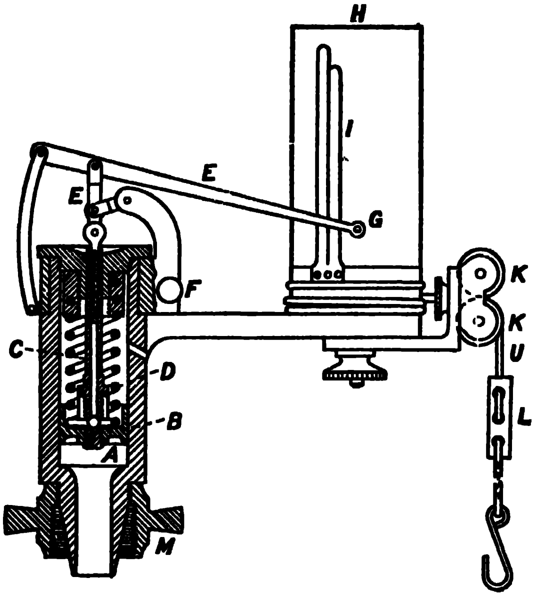


FIG. 25.—Crosby steam-engine indicator.

A = Cylinder.
B = Piston.
C = Piston-rod.
D = Spring.
E = Parallel motion.
F = Handle for moving pencil.
G = Pencil.
H = Drum.
I = Clips for paper.
U = String.
K = Guide pulleys.
L = Lengthening slide for string.
M = Nut with right and left-hand screw thread for attaching indicator to engine.

The paper on which the diagram is to be drawn is wrapped round a drum *H*, and held in place by the clips *I*. The drum is then made to turn backwards and forwards with a motion exactly proportional to that of the engine piston, and the pencil, which is lightly pressed against the paper, is made to rise to a height representing the pressure of steam in the engine cylinder.

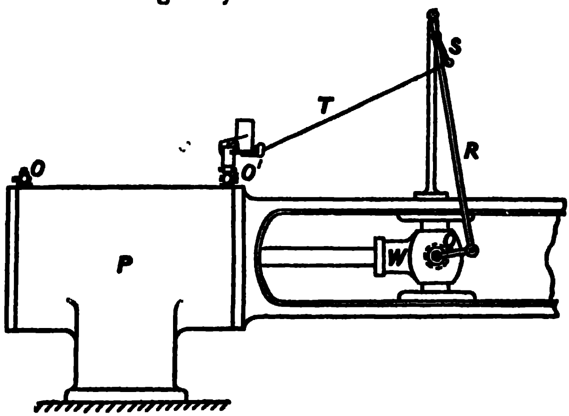


FIG. 26.—Method of fixing indicator on a horizontal engine.

P = Engine cylinder.
W = Cross-head.
O, *O'* = Indicator cocks.
Q, *R*, *S* = Links for obtaining reduced copy of motion of piston.
T = Indicator cord.

The motion of the drum is obtained as follows:—A short link *Q*, Fig. 26, is coupled to the end of the cross-head pin and to the long pendulum link *R*. An arm *S* is clamped near the top of *R*. *S* has a looped string attached to it, on to which the short indicator cord may be hooked.

If the string is at right angles, at half stroke, to a line joining its upper extremity with the pivot of *R*, its motion will be an almost exact reduced copy of that of the cross-head, and therefore of the engine piston. It will transmit this motion to the drum round which it passes.

The length of the string may, if necessary, be adjusted by the sliding plate *L* (Fig. 25).

The drum contains a spring which is wound up on the out stroke, and so keeps the string tight on the return stroke. The cord used must be as inelastic as possible, even a small amount of stretching in it will cause the drum to lag behind its proper position on the out stroke (when the tension is greatest) more than on the return stroke, and so will reduce the size of the diagram drawn.

The pencil *G* moves vertically, its motion being an enlarged copy of that of the piston *B*, to which it is connected through the links *E*, *E*.

The piston *B* works in the small cylinder *A*, which is connected with either end of the engine cylinder by screwing the right and left-handed nut *M* on to one or other of the cocks *O*, *O′*. These are three-way cocks. When they are turned in one direction *A* is in connection with the atmosphere, and when they are turned in the other direction it is connected with the engine cylinder. In the latter case the pressure on the indicator piston is obviously the same as that on the engine piston.

Cocks *O* and *O′* are often connected by a pipe to which the indicator is fixed. This saves trouble, but it is a bad arrangement, as there is a loss of pressure in the pipe, due to condensation and wire-drawing.

The spring *D* is clamped to the piston at one end and fixed to the cylinder cover at the other. It is compressed by the pressure of the steam, and allows the piston, and therefore the pencil, to rise.

Different springs may be put in for different pressures. They are tested by the makers and marked with a fraction. Thus, if a spring is stamped $\frac{1}{100}$, it means that it will allow the pencil to rise $\frac{1}{100}$ of an inch for every pound pressure per square inch on the piston.

The upper end of the cylinder has some holes in it, to allow air and any leakage of steam to escape.

The pencil may be pressed lightly against the paper by turning the whole link work round the top of the cylinder by the handle *F*.

The piston, spring, and other moving parts, are all very

light, otherwise the sudden variations of steam pressure would set them vibrating in such a way that the pencil would draw wavy lines instead of smooth ones. There is an indication of such vibrations at *D*, Fig. 24. If there is too much friction, these parts will move jerkily.

An indicator diagram shows the pressure on one side of the piston only, *i.e.* it shows the forward pressure on one stroke, and the back pressure on the next. To get the effective pressure at any point we must take the forward pressure from a diagram taken at one end of the cylinder, and the back pressure from one taken at the other. For finding the horse-power, however, all we want to learn from the indicator is the mean effective pressure throughout both the out and the in strokes, and that is given just as accurately by taking the mean height of the diagrams for these strokes as they are drawn, as by taking the mean of the real effective pressures measured from the upper line in one diagram to the lower line in the other.

Ex. 1.—The stroke of an engine is 10 inches. If steam is supplied to it at 30 pounds by gauge, find when it must be cut off to obtain a pressure of 5 pounds at the end of the stroke.

$$r' = 10$$
$$P' = 5 + 15 = 20$$
$$P = 30 + 15 = 45$$
$$\text{but } P\,r = P',\, r'$$
$$\text{or } r = \frac{P'\,r'}{P} = \frac{10 \times 20}{45}$$
$$\therefore\ r = 4{\cdot}44 \text{ inches.}$$

$\therefore$ Steam must be cut off at 4·44 inches of the stroke.

Ex. 2.—An engine with a piston 12 inches in diameter and 18 inches stroke, was working at 100 revolutions per minute. Indicator diagrams were taken with a $\frac{1}{40}$ spring, and their mean heights were 1·24 and 1·32 inches. What "indicated horse-power" was the engine developing?

Mean height of the two diagrams $= \dfrac{1{\cdot}24 + 1{\cdot}32}{2} = 1{\cdot}28.$

$\therefore$ Mean effective pressure $= 1{\cdot}28 \times 40$ pounds per square inch.

$\therefore$ Total mean effective pressure $= 144 \times {\cdot}7854 \times 1{\cdot}28 \times 40$ pounds.

Distance travelled by piston per minute $= 1\frac{1}{2} \times 2 \times 100$ feet.

$\therefore$ Work done per minute

$$= 144 \times {\cdot}7854 \times 1{\cdot}28 \times 40 \times 1\tfrac{1}{2} \times 2 \times 100 \text{ foot pounds.}$$

$$\therefore \text{I.H.P.} = \frac{144 \times {\cdot}7854 \times 1{\cdot}28 \times 40 \times 1\frac{1}{2} \times 2 \times 100}{33{,}000}$$

$$= 52{\cdot}6.$$

9a. Indicator for High Speed Engines.—With the growth in the speed of engines which has taken place in recent years the moving parts of the indicator have had to be made lighter. With a slow speed engine the pointer of Fig. 25 can accurately follow the variations of steam pressure; but the more rapid these variations become the greater is the error introduced by the inertia of the moving parts. The pointer indications lag always a little behind the pressure.

Consider a sudden rise of pressure as with an explosion. It takes a little time for the pointer to respond and the diagram will show the explosion not quite in its true place, but a little delayed. When the pointer does move, however, in response to the explosion pressure, it moves rapidly, and it does not stop when it reaches the real indication of the pressure, but overshoots the mark.

The total area of the diagram is not much altered by this action, but for study of what is actually taking place in the cylinder the weight of the moving parts must be reduced to a minimum. The piston weight is not so serious as the pointer weight, and for this reason the pointer is abolished in some indicators and a beam of light used instead.

Fig. 26*a* is a simplified diagram of an indicator of this type, the Hopkinson Flashlight Indicator. On the right hand is a side view of the springs, mirror and spindle. A number of details are omitted, in order that the action may be made clear.

The block *C* is screwed into the cylinder and the pipe *H* brings the pressure to the piston *P*. The motion of the piston is transmitted to a stiff spring *S*, and from this by a fine spring *V* to the lever arm *M*. This arm rocks a small mirror *R* mounted on a spindle *I*. A small beam of light falls on *R* and is reflected on to a ground glass screen or a photographic plate. This reflected beam is the pointer, and, as the mirror rocks, the spot where the beam strikes the screen moves up and down. This movement of the spot indicates the pressure changes in the cylinder, in the same way as the end of the pointer indicates them in the indicator shown in Fig. 25.

In Fig. 25 the paper moves horizontally with the engine piston movement, but in the Flashlight Indicator the screen is fixed and the necessary horizontal movement is provided by rotating the block *D* (with the piston, supports, and mirror) about *C*. Ball bearings and springs (not shown) are provided to make this movement free, and a rod screwed into *D* is connected with an indicator cord fitted up similarly to that shown in Fig. 26.

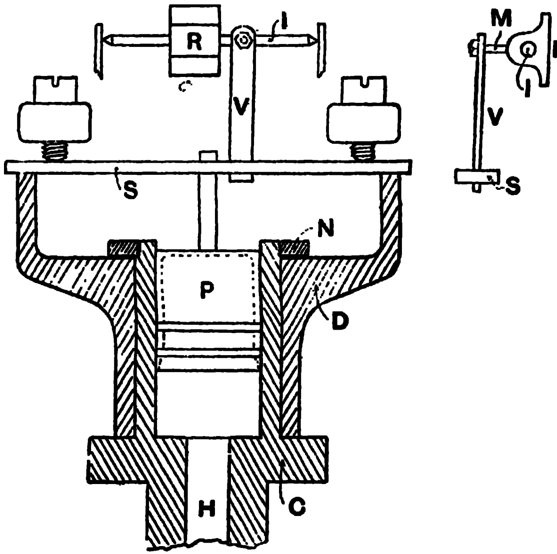


FIG. 26a.

We thus get two movements, the vertical movement of the spot of light on the screen showing the pressure in the cylinder, and the horizontal movement showing the movement of the engine piston, and a curve is drawn by the spot. This curve is the indicator diagram.

If the screen is a photographic plate we get a permanent

record. If the screen is ground glass and the engine speed is sufficiently high (not less than 200 revs. per min.), we see the diagram on the screen and can either observe its changes or sketch it in with a pencil as required.

EXAMPLES II.

1. State Boyle's law, pointing out carefully the conditions under which it is true.

2. Describe an experiment for demonstrating Boyle's law.

3. Why is the rule, $PV =$ constant, not exactly true for steam, when expanding in an engine?

4. Two engines working at the same speed are supplied with steam at 40 pounds pressure per square inch, by gauge. Their cylinders are 9 inches and 12 inches in diameter, the stroke in each case being 18 inches. In the smaller engine steam is admitted during the whole stroke, and in the larger for half the stroke only. Which engine (*a*) does the more work, (*b*) uses the most steam?

5. Calculate the final pressure in an engine cylinder, when steam is admitted at 40 pounds pressure per square inch, absolute, and cut off at $\frac{5}{8}$ of the stroke.

6. Draw the expansion curve for the above case geometrically.

7. If, in example 5, the steam is allowed to escape at 18 pounds pressure (absolute), find the mean effective pressure on the piston.

8. If steam is supplied to an engine at 85 pounds pressure by gauge and cut off at $\frac{1}{5}$ of the stroke, calculate the pressure at $\frac{2}{5}$, $\frac{3}{5}$, $\frac{4}{5}$, and the end of the stroke.

9. Plot the expansion curve in example 8 on squared paper.

10. What is the rule for finding the mean height of an indicator diagram by ordinates? How is the rule deduced?

11. What is meant by clearance, and what are its effects?

12. Explain the term "*wire-drawing*." What steps are taken to avoid it in engines fitted with a simple slide-valve?

13. Given a pair of indicator diagrams, what other data do you require to determine the indicated horse-power of an engine?

14. The lengths of the ordinates of a pair of indicator diagrams taken with a $\frac{1}{40}$ spring were as follows—

Front end.	Back end.
·14	·74
·19	1·07
·26	1·07
·34	1·01
·50	·85
·72	·59
·97	·42
1·08	·33
1·09	·22
1·10	·16

The stroke of the piston was 18 inches, and its diameter 12 inches. The shaft was making 90 revolutions per minute. At what horse-power was the engine working?

15. Show, by means of a sketch, the method of fixing an indicator to a horizontal engine.

16. The diameter of the cylinder of an engine is 30 inches and the stroke of the piston is 4 feet. If steam is admitted at an absolute pressure of 70 pounds per square inch, and is cut off when the piston has travelled one foot, what would be the total pressure on the piston at the point of cut-off, and also when the piston has travelled 2 feet, 3 feet and 4 feet respectively?

Take the simplest law of expansion.

Why is it economical to cut off steam before the end of the stroke? (S. and A. 1897.)

17. Steam enters a cylinder at 180 pounds pressure per square inch (absolute), is cut off at one-third of the stroke, and expands according to the law "PV=constant." Find the average pressure absolute during the forward stroke, neglecting clearance. If the back pressure is 17 pounds (absolute) per square inch, what is the average effective pressure? If the area of the cross section of the cylinder is 112 square inches, and the stroke is 24 inches, what work is done in one stroke? (S. and A. 1900.)

18. Find, by the method shown in Fig. 22, the mean pressure represented by the diagram in Fig. 24. The latter was taken from an engine with a piston 13½ inches diameter and 18 inches stroke. Find the pressure of the steam supplied to this engine and the work done per stroke.

19. Describe an indicator, and how it is attached to a steam-engine. Sketch the sort of diagram obtained. Show how the horse-power is calculated. (S. and A. 1898.)

CHAPTER III.

MATERIALS USED BY ENGINEERS. THE PARTS OF AN ENGINE CONSIDERED IN DETAIL.

10. Iron and Steel.—The material most used in engine building and also in boiler making is iron, either pure or combined with small quantities of carbon and other elements.

Iron can be produced in forms which differ widely from one another in their properties, and which are, therefore, suited for a large variety of purposes. Thus, cast iron can be melted and run into moulds, but it is brittle and will not withstand shocks, while wrought iron becomes soft and pliable, but not fluid, when hot and can be rolled into bars which, even cold, will bend double without breaking.

The great drawback to the use of iron, in any form, is that it corrodes in moist air, forming a red oxide, or rust, which scales off, leaving a rough surface.

Minerals containing a large proportion of iron are found in different parts of Great Britain, America, Germany, Sweden, and Spain. These are heated to a very high temperature, with coke, in a blast furnace, a certain amount of lime being added to assist in the fusion and chemical decomposition which takes place. The metal is separated and collects as a liquid at the bottom of the furnace, whence it can be run off through a small hole and cast into bars called "pigs." These are either used at once as CAST IRON, or are converted into WROUGHT IRON and STEEL.

(*a*) **Cast Iron** varies in quality according to the ore from which it is made. Its strength is increased by remelting it once or twice before use.

As employed by engineers, it is a greyish metal, showing a close crystalline fracture when broken. It contains 3 to 4 per cent. of carbon, but only about $\frac{1}{8}$ of this is actually combined with the iron. The remainder is merely dissolved in it.

It melts readily at high temperatures. The more uncombined carbon it contains, the thinner is the resultant liquid. There is, however, a corresponding loss of strength in the solid iron.

The first step in making a casting, is to prepare, with the aid of a wooden pattern, a mould in foundry sand, or loam, of the exact form required. Into this the molten metal is poured, care being taken that the air can escape freely, and that no scum can collect in any part.

The design should be such that the iron will cool at the same rate throughout, for in cooling it contracts, and any part contracting after the rest is hard, will tend to crack off.

Among the larger parts of an engine which are made of cast iron, are the frame, cylinder, cylinder covers, slide-valve, piston, and fly-wheel.

(*b*) **Wrought Iron** is made from cast iron, by removing the carbon. In the process of manufacture, it is repeatedly rolled into bars, which are cut into lengths, piled crosswise, heated, and rolled again, so that it becomes tough and fibrous.

It can be welded at a white heat, and is therefore suitable for making complicated forgings.

It is used for connecting-rods, piston-rods, eccentric-rods, etc., and also for bolts and nuts.

(*c*) **Steel** is pure iron, combined with a very small quantity ($\frac{1}{2}$ per cent.) of carbon, but containing no carbon in solution. It can be rolled into bars or rails, and is at once stronger and more ductile than wrought iron. It can also be cast in moulds, but it contracts much more than cast iron in cooling.

It is used for boiler plates, rivets, shafting, etc., and often replaces wrought iron for piston, valve, and connecting-rods. Large pistons, cross-heads, and eccentrics are sometimes steel castings.

Steel containing more than $\frac{1}{2}$ per cent. of carbon is manufactured. It is very strong and possesses the property of becoming extremely hard, but brittle, when heated to redness and plunged into water. This makes it invaluable for cutting tools, but prevents its use in boiler-work.

Small quantities of nickel, manganese, or aluminium are often added to steel to increase its strength and toughness.

11. Other metals.—Besides iron, the engineer uses copper, bronze, brass, and white metal, but all these are much more expensive.

(*a*) **Copper** is a reddish metal, soft and ductile when pure. It is used for making pipes, and also, since it is a good conductor of heat, for the fire-boxes of locomotives.

(*b*) **Bronze** is the general name applied to mixtures of from 80 to 90 per cent. of copper, with tin, and a small proportion of zinc, manganese, aluminium, or phosphorus. These alloys are as strong as steel. They can be cast or rolled, and, as they corrode but little, they are largely used at sea for pumps, propeller blades, etc.

(*c*) **Brass** is composed of two parts of copper and one of zinc. It is not very strong, but is easily worked, takes a good surface, and does not corrode. It is therefore used for lining glands, for shaft bearings, and for small castings generally.

(*d*) **White metal** consists principally of tin, mixed with copper and antimony. It melts easily, is very soft, and takes a smooth surface. It is used for lining the working parts of an engine, such as the bearings and cross-head, to reduce friction.

12. The strength of metals and alloys.—The following table of loads considered safe in engine and boiler work, when no allowance has to be made for bending and other secondary stresses, will give the reader an idea of the relative strength of the above metals—

Material.	Safe working stress in pounds per square inch.	
	Tension.	Compression.
Cast iron	3,000	10,000
Wrought iron	8,000	8,000
Mild steel	10,000	10,000
Cast steel	16,000	16,000
Copper	2,500	2,500
Bronze	10,000	10,000
Brass	2,500	2,500

13. Engine Frames.—Having considered the materials of which engines are built, we must now discuss their various parts in detail, beginning with *the Frame* (see *F*, Figs. 13, 14, and 15). This may be made of one piece of cast iron, or constructed with sections of rolled steel.

In stationary engines, it rests on a brick or concrete foundation, while in marine engines it is bolted to a special framework built into the ship.

It must be rigid, and not liable to become distorted under any forces that may act upon it.

One end supports the crank-shaft, either wholly, with two bearings, or in part, as shown in Fig. 14.—The latter design necessitates a **pillow block** on a separate foundation, and this may get out of line and cause trouble.—The other end is formed into a cylinder cover, or simply a flange, to which the cylinder is bolted.

Part of the frame is usually made to serve as cross-head guides, but these may be separate bars, 1, 2, or 4 in number, held in place by lugs cast onto the cylinder cover, and by an open bracket. The latter arrangement is used in locomotives.

The frame in Fig. 13 is hollow like an inverted trough, the iron being three-quarters of an inch thick. There is a broad flange round the bottom, upon which the frame rests, and three lugs are formed on each side, for the foundation bolts. The metal is carried up at each side to support the cylinder cover, which has to bear the whole weight of the cylinder, as well as the steam pressure.

Fig. 27 shows another design of frame used for large horizontal engines. Here the cylinder rests directly on the foundations, and supports the frame. The forces which the latter has to withstand are therefore—

1. Bending due to its own weight.
2. Bending due to the pressure on the guides.
3. Tension and compression caused by transmitting the force on the piston to the crank.

The right-hand part is box-shaped, having a rectangular cross-section. The left-hand part is cylindrical, and open

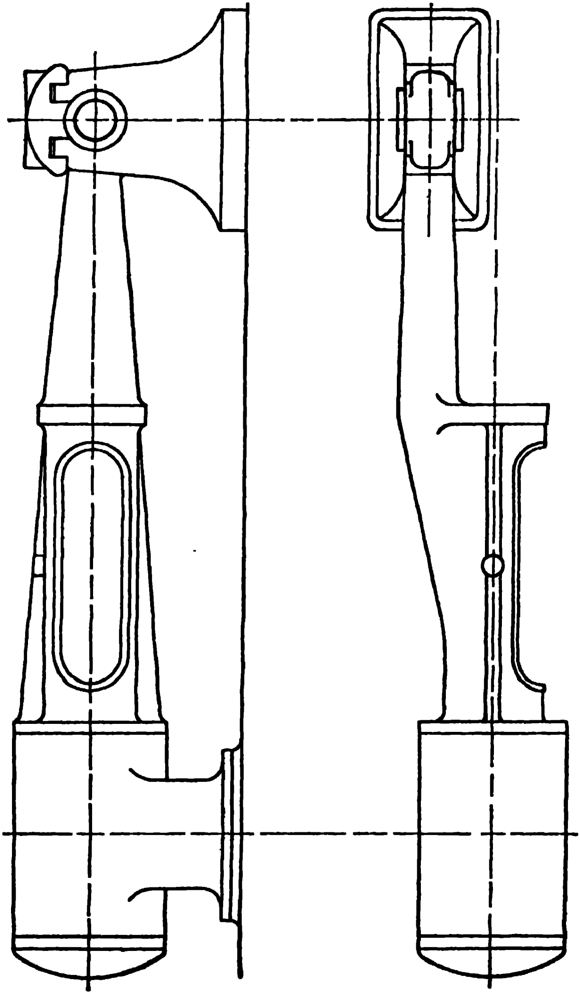


FIG. 27.—Corliss type of engine frame.

at the front and end. The interior of the latter forms a double cross-head guide.

In most vertical engines the cylinder is held in place, on one side by a cast-iron column (see Fig. 28), and on the other by a steel strut. In this arrangement all the working parts are easily accessible.

Since the strut has to withstand both tension and compression, it must be fixed with large nuts, with bolts passing through a broad flange, or with cotters (as described in connection with the cross-head.)

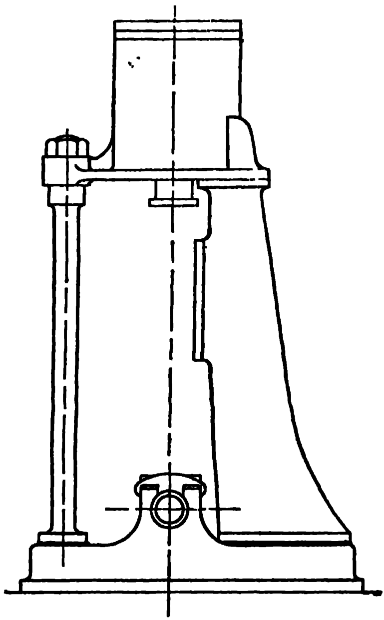


FIG. 28.—Marine type of engine frame.

14. The Cylinder and Valve-Chest.—These together form a single casting, in making which the best iron obtain-

able is used. A longitudinal section through both is given in Fig. 14, and a perspective sketch, including a cross-section, is shown in Fig. 29. Further details of the valve-chest can be seen in Fig. 15. The same reference letters are used in all the above diagrams (for other designs see Figs. 23, 105 and 114).

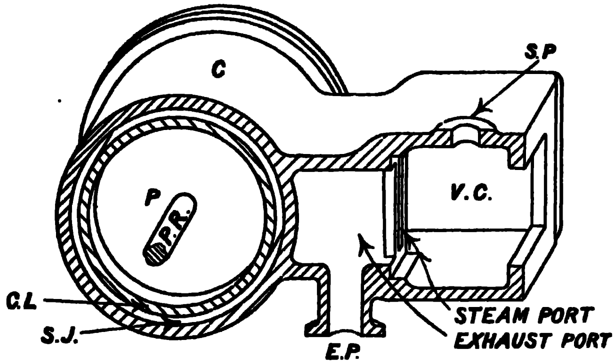


FIG. 29.—Cross-section of the cylinder shown in Fig. 14.

The cylinder liner *CL* is made of cast iron, or cast steel. It is turned at the ends to a tight fit, and is forced into its place in the cylinder by a hydraulic press. In small engines the steam-jacket can be rendered perfectly steam-tight in this way. In large engines, one cover is usually cast with the cylinder; the liner then has a small internal flange, which is bolted to this cover, and the joint at the other end is made by driving a ring of copper into a groove prepared for it.

The extremities of the cylinder barrel (or the liner where one is used) are bored out rather larger than the rest. This chamfering begins at a point just reached by the piston. It prevents a ridge being left there when the remainder of the cylinder has become worn. The covers (see Fig. 14) are made to conform as nearly as possible to the two sides of the piston, to reduce the clearance. Sometimes they are

hollow, and form additional steam jackets. They are recessed opposite the port openings, to leave a free passage for the steam.

The uses of the steam and exhaust ports have been stated in Chapter I. These passages are rectangular in cross-section (see Figs. 15 and 29). In elevation (see Fig. 14) they are curved in such a manner as to open at right angles to the face on which the slide-valve *V* works, thus avoiding sharp edges.

The form of the valve-chest is of no great importance, but its cover must be large enough to admit the valve.

It is very difficult for a beginner to realize from drawings the exact shape of this complicated casting. He must examine an actual cylinder for himself, by passing wires through the ports to determine their shape, and measuring the thickness of the metal, where possible.

It is important to notice how uniform the latter is. If it were not so the thinner portions would solidify first in the mould, and the thicker parts, in cooling and contracting afterwards, might break away from these.

It is an excellent exercise to measure the clearance volume of such a cylinder.

15. Stuffing-Boxes.—The object of these is, as previously mentioned, to prevent steam from escaping round the piston-rod and valve-rod.

Fig. 30 shows two views of a piston-rod stuffing-box. *C* is a projection cast on the cylinder cover. *G* is the gland, made of cast iron, and lined with brass to reduce friction. Pressure is applied through this to the packing (not shown), by tightening the nuts *N*, *N*. The second pair of nuts are then locked tight against the first pair, and hold them in their place upon the screw.

Two studs are sufficient for adjusting small glands. In large ones, three or four studs are used, and the flange is made circular.

B is a brass bush which can readily be replaced when worn.

Of the various forms of packing enumerated in Chapter I, namely hemp, asbestos, and soft metal, the latter is the best, as it causes less friction and requires less attention

than the others. It is inserted in the form of divided rings, which are *V*-shaped and fit into one another. Small springs, or a few turns of hemp, are placed on the top of these rings to provide the necessary elasticity.

The valve-rod gland is similar in design to Fig. 30, but, being smaller, it is made entirely of brass.

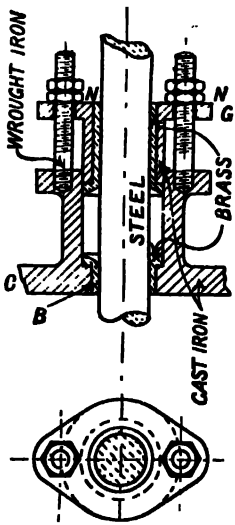


FIG. 30.—Piston-rod stuffing-box.

Fig. 30A shows a more elaborate arrangement of metallic packing suitable for large piston-rods. This reduces friction to a minimum, and will remain steam-tight for long periods.

The inner (right hand) part is formed of three open rings of white metal. The outer part consists of two pairs of blocks of white metal set in brass slides. Each part is mounted in loose independent carriers which are held together by springs; thus the gland does not constrain the piston-rod rigidly, but allows it a small amount of lateral freedom to compensate for wear, for distortion due to expansion of the cylinder by heat, and for slight errors in the original alignment of the engine. A lubricator is provided at *L*, and a drain cock, to dispose of any accumulation of water, at *D*.

16. The Piston and Piston-Rod.—The piston is made of cast iron. One method of rendering it steam-tight has been described in Chapter I. A second method is shown in Fig. 31 which is a section of a locomotive piston.

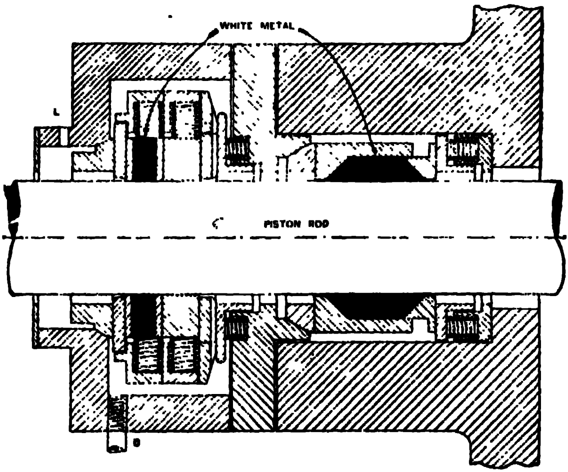


FIG. 30A.—The "United States" type of metallic packing.

In the latter the two cast-iron rings *R* (called Ramsbottom rings) are themselves the springs. They are turned to a rather greater diameter than the cylinder in which they have to work, and are then cut across, and sprung into grooves on the piston.

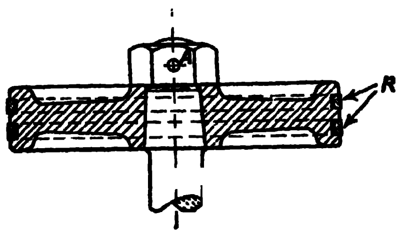


FIG. 31.—Piston of a locomotive.

The total steam pressure on large pistons is very great, and to withstand it they have to be made conical, or else box-shaped, with internal radial ribs.

Ex. 1.—Find the total force on the low-pressure piston of a triple expansion engine 80 inches in diameter, when the maximum effective pressure is 20 lbs. per square inch.

$$\text{Area of piston} = 80^2 \times \cdot 7854$$
$$= 5026 \text{ sq. ins.}$$
$$\therefore \text{ Total pressure on piston} = 20 \times 5026.$$
$$= 100{,}520 \text{ lbs.}$$
$$= 45 \text{ tons nearly.}$$

Fig. 32 shows, partly in section and partly in elevation, the large cast-steel piston of a marine engine (see also Fig. 114). This material is much stronger, weight for weight, than cast iron.

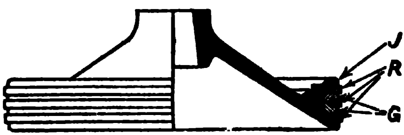


FIG. 32.—Cast-steel marine engine piston.

The three "spring" rings *R* are far too large to be simply "sprung" on. They must be got into place by removing the junk ring *J* and the two guide rings *G*.

The *piston-rod* has, of course, to support the same pressure as the piston. It has to be made of larger diameter than would at first appear necessary, to prevent it bending. Fig. 31 shows a common method of attaching the piston-rod to the piston, and one which allows of their being taken apart for repairs. The rod is enlarged and fitted to a conical hole in the piston. Its end is turned down parallel, and threaded to take a large nut which holds it firmly in place, and is prevented from working loose by the split pin *A*.

17. The Cross-head and Cross-head Guides.—The cross-head may be forged on the end of the piston-rod (see Fig. 34), or it may be a separate piece as shown in Fig. 13 and, to a larger scale, in Fig. 33. Here the end of the piston-rod *P.R* is slightly coned, and enters a conical hole in

the cross-head, where it is held firmly in place by a tapered cotter *C*.

A cast-iron shoe *S* is used to work on the face of the guide, as cast iron does not wear into grooves as would wrought iron or steel.

The brass bush for the pin in the connecting-rod is in two parts, which can be adjusted for wear by a set screw.

Fig. 34 shows a locomotive cross-head for four guide-bars. It is forked, and carries a steel pin on which the bush in the connecting-rod end turns.

It is the oblique pressure of the connecting-rod that makes cross-head guides necessary. The shorter the rod, the greater will be its inclination, and, therefore, it is rarely made less than twice the piston-stroke in length.

The pressure is in one direction only, as will be seen from Fig. 35, where the forces *P*, from the piston-rod, and *C*, from the connecting-rod, and their resultant *R*, are indicated in two positions. Thus, in marine engines, which have to be reversed for short periods only, a single guide (with cover-plates to give a slight support from the front, as in Fig. 33) is found to be sufficient; while in locomotives which run regularly at full power, in either direction, guides on both sides are the rule.

The shoe of the cross-head is often lined with white metal, and, to insure thorough lubrication, grooves are cut in its face to distribute the oil.

Under certain circumstances, such as a sudden reduction of steam pressure, the forces shown in Fig. 33 might become reversed. Some support for the cross-head is, therefore, always provided on the upper side.

Ex. 2.—In Example 1, the piston-rod of the engine is $7\frac{1}{2}$ inches in diameter. Find the force upon it per square inch.

$$\text{Area of rod} = (7\tfrac{1}{2})^2 \times \cdot 7854$$
$$= 44\cdot 18 \text{ sq. inches}$$
$$\text{Total force on rod} = 100{,}520 \text{ lbs.}$$

$$\therefore \text{Force on rod per square inch} = 100{,}520 \div 44\cdot 18$$
$$= 2{,}275 \text{ lbs. per sq. inch.}$$

NOTE.—This stress is less than that given in the table, which only applies to bars too short to fail by bending.

18. Acceleration of Moving Parts of an Engine.—Every one is familiar with the fact that force is required to change the velocity at which a body is moving. This law must be remembered in connection with the piston, piston-rod, and cross-head of an engine, as these have to be set in motion at the beginning, and checked at the end, of every stroke.

The unit of force has been defined (p. 22) as the weight of one pound. The unit of rate of change of velocity is a change of one foot per second in every second. Rate of change of velocity is called **acceleration.**

If, for example, a locomotive changes its speed from 45 to 60 miles per hour in 10 seconds, its **acceleration** is—

$$\frac{60-45}{10} \text{ miles per hour per second.}$$

$$= \frac{15}{10 \times 60 \times 60} \text{ ,, per second ,,}$$

$$= \frac{15 \times 1760 \times 3}{10 \times 60 \times 60} \text{feet ,, ,,}$$

or 2·2 feet per second per second.

Now the force of gravity has been experimentally proved to increase the velocity of any falling body by 32 feet per second per second (approximately). In other words, a force of W lbs., say, acting upon a weight of W lbs. gives to the latter an acceleration of 32 feet per second per second. Therefore unit acceleration would be given to a weight of W lbs., by a force of $\frac{1}{32}W$ lbs., or, speaking generally, the acceleration f given by a force P to a weight W is expressed by the formula

$$f = \frac{P}{\frac{1}{32}W}$$

Ex. 3.—A piston weighing 400 lbs. has, at the commencement of its stroke, an acceleration of 20 feet per second per second. Find the total steam pressure required to produce this.

$$f = \frac{P}{\frac{1}{32}W}$$

$$P = \tfrac{1}{32} W f$$

$$\therefore P = \tfrac{1}{32} \times 400 \times 20$$

$$= 250 \text{ lbs.}$$

In an engine the velocity and acceleration of the piston vary from point to point of the stroke. These variations are shown graphically in Fig. 35A. AB represents the stroke of the piston, B being the crank end. The velocity of the piston at each point is represented by the ordinate to the curve ACB, and its acceleration by the ordinate to the curve DEF.

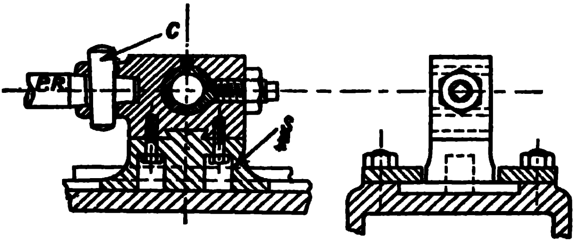


FIG. 33.—Cross-head to work on a single guide.

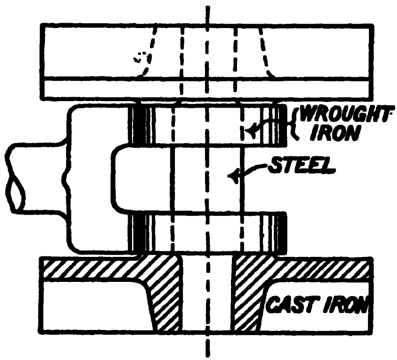


FIG. 34.—Locomotive cross-head.

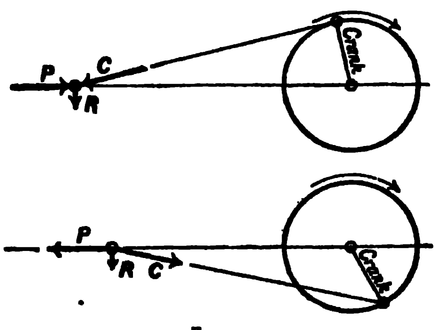


FIG. 35.

It will be noticed that the acceleration is greatest when the velocity is zero, and vice versa. The maximum values of the acceleration are $\left(1 + \frac{R}{L}\right)\frac{V^2}{R}$ at the outer end and $\left(1 - \frac{R}{L}\right)\frac{V^2}{R}$ at the crank end of the stroke, where :—

R = the crank radius in feet.
L = the length of the connecting-rod in feet.
V = the velocity of the crank-pin in feet per second.

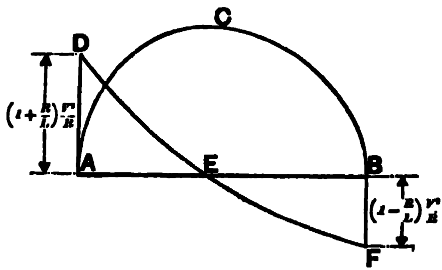


FIG. 35A.—Curves of piston velocity and acceleration.

Ex. 4.—An engine has a piston weighing 210 lbs., its stroke is 2 feet, its connecting-rod is 5 feet long, and it makes 240 revolutions per minute. Find the force required to check the motion of the piston at the end of each out stroke.

$$\text{Force } P = \frac{Wf}{32}$$

$$f = \left(1 + \frac{R}{L}\right)\frac{V^2}{R}$$

$$\therefore P = \left(1 + \frac{R}{L}\right)\frac{V^2}{R}\,\frac{W}{32}$$

$$= \frac{6}{5} \times \left(\frac{22 \times 2 \times 4}{7}\right)^2 \times \frac{210}{32} = 4{,}978 \text{ lbs.}$$

EXAMPLES III.

1. What is the difference between cast iron and wrought iron?

2. Name two parts of an engine which are made of (*a*) cast iron, (*b*) wrought iron, (*c*) steel, (*d*) brass.

3. Why is a piston-rod gland lined with brass?

4. Compare the properties of bronze with those of steel. Why is the former not more used?

5. Why is copper used for locomotive fire-boxes?

6. Sketch three views of a horizontal engine frame.

7. How is a cylinder jacket made steam-tight?

8. A cylinder cover 10 inches in diameter is attached by 12 studs $\frac{5}{8}$ inch diameter at the bottom of the thread ($\cdot 3$ square inch in area). Find the force per square inch in these, when the steam pressure is 100 lbs. by gauge.

9. The valve-chest cover of the engine in question 8 is 10 inches by 15 inches. How many similar studs should be used to secure it?

10. Sketch one end of a cylinder, showing the cover and steam-port.

11. Sketch a cross-section of a cylinder and valve-chest at one-third of its length from either end.

12. How is the piston-rod fixed to a piston? Give a sketch.

13. The maximum pressure on a piston 7 inches in diameter is 200 lbs. per square inch, The piston-rod is 2 inches in diameter. Find the force per square inch upon it.

14. How would you proceed in order to remove the piston-rod of the engine in Fig. 13, and to put a new one in its place?

15. How may a piston-rod be fixed to a cross-head?

16. Sketch two views of a cross-head forged in one with the piston-rod.

17. How are the bushes of a cross-head adjusted for wear?

18. Indicate, by an arrow, in which direction the engine in Fig. 28 should run.

19. Make a sketch, and describe the construction of one form of piston cross-head with which you are acquainted. Under what conditions may a slipper-slide for the piston cross-head be employed in a horizontal engine? (S. and A. 1896.)

20. Sketch and describe briefly the construction of a piston, showing how it is made steam-tight. (S. and A. 1898.)

21. When starting, a locomotive exerts a tractive force of 4 tons upon a train weighing 200 tons. Calculate the acceleration (neglecting friction), and the velocity after 1 minute.

22. A piston and rod and cross-head weigh 330 lbs. At a certain instant, when the resultant total force due to steam pressure is 3 tons, the piston has an acceleration of 370 feet per second per second in the same direction. What is the actual force acting on the cross-head? (S. and A. 1902.)

CHAPTER IV.

THE PARTS OF AN ENGINE CONSIDERED IN DETAIL.

19. The Connecting-Rod.—As stated in the preceding chapter, the length of this determines the pressure on the guide bars. It is round or rectangular in section, and is forged out of wrought iron.

The form of its smaller or cross-head end depends upon the design of the cross-head. When the pin is fixed to the latter, the connecting-rod end is fitted with brasses; otherwise the arrangement shown in Fig. 14 is adopted.

The crank end, in what is called the "marine type" of connecting-rod (see Figs. 14 and 36), consists of a pair of brass blocks, with an iron cover-plate, secured by strong bolts, which, on the in-stroke of the piston, have to bear the whole force of the steam.

Adjustment for wear is simplified by inserting between the brasses two liners (Fig. 37), held in place by small pins. When the nuts are loosened these can be slipped out and filed down. This device saves taking the rod to pieces.

Lock-nuts are used on the bolts, and a split pin is inserted beyond them as an additional safeguard.

In marine engines where space has to be economised, a different method of locking (see Fig. 38) is adopted. The under part of the nut is turned down, and fits into a corresponding recess, where it is kept from rotating by a small set screw.

Another form of connecting-rod end is used in some horizontal engines, and in locomotives, where the crank-pin is short and of large diameter (see Fig. 39). Here the brasses are enclosed in a horseshoe strap bolted to the forged body of the rod, and are adjusted by means of a tapered cotter, which can be locked with two set screws *S*, *S*.

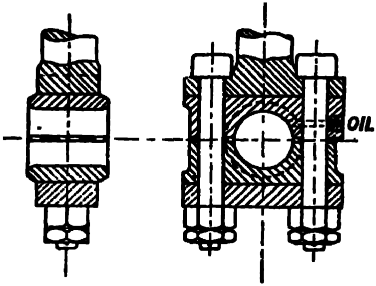


FIG. 36.—Marine type of connecting-rod end.

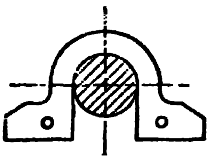


FIG. 37.— Liner for marine connecting-rod.

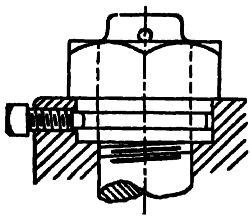


FIG. 38.—Method of locking nuts used in marine engines.

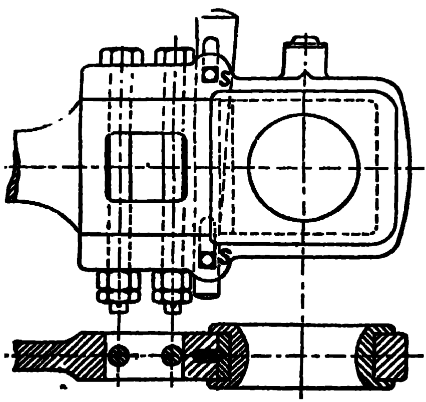


FIG. 39.—Locomotive connecting-rod as used on the Midland Railway.

Nuts have to be locked when they cannot be tightened up firmly in the first instance, or if they require to be removed frequently. Thus, single nuts are sufficient for a cylinder cover, but double nuts are shown in Fig. 36, and locking screws in Fig. 44, because, if the first nut were screwed down tight on to the "keep," the brasses would grip the journal between them so firmly that it could not revolve.

20. The crank is the last link between the piston and the shaft. In its simplest form (Fig. 40) it is an arm of wrought iron, or cast steel, fixed to the end of the shaft, and having a steel pin inserted in it. It is kept from turning on the shaft by a key, which is a rectangular bar of steel, embedded half-way in each. Though small, this will transmit a great force, for it would have to be sheared throughout its whole length before slipping could take place.

The pin is made to fit very tightly in the hole prepared for it, but it can easily be inserted in the latter when the crank arm is expanded by heat; or it may be forced into its place with a hydraulic press. Its end is riveted over as an additional safeguard.

The "*throw*" of the crank is the distance between the centres of the crank-pin and shaft. It is half the piston-stroke.

A complete cast-iron disc is frequently used (see Figs. 14 and 41) instead of an arm. This is hollowed out at the back, as indicated by dotted lines, leaving a large mass of metal opposite the crank-pin, so as to balance the weight of this and of the connecting-rod end.

The balancing of the moving parts of an engine is very important, especially at high speeds. The effect of an unbalanced crank may be felt by holding up the back end of a bicycle, and spinning the wheel round with one pedal removed. Replacing the other pedal will make the machine run more smoothly, but the two would have to rotate in the same plane to balance each other perfectly.

In marine engines the three or four cranks are set at different angles, so as to balance as nearly as possible, and in locomotives weights are inserted in the wheels with the same object. The effect of the backward and forward motion of the piston, piston-rod, and cross-head is more difficult to deal with. These reciprocating parts can only be satisfactorily balanced by a second similar set of reciprocating parts moving always in the opposite direction. This is why so many fast-running engines have two cylinders, with the cranks set opposite one another.

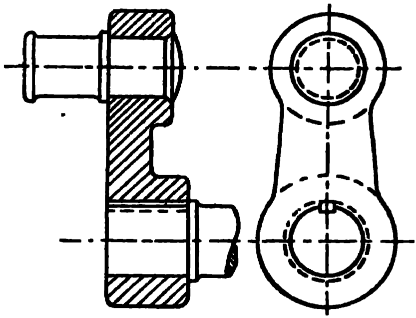


FIG. 40.—Wrought-iron overhung crank.

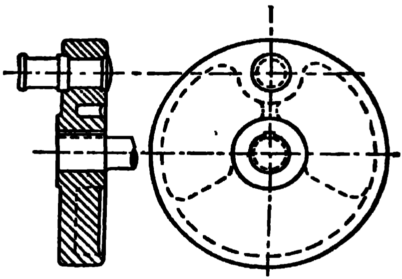


FIG. 41.—Cast-iron balanced crank-disc.

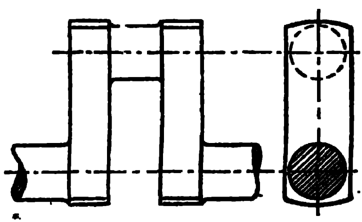


FIG. 42.—Forged cranked shaft.

In a double crank or cranked shaft (see Fig. 42) the forces are better distributed. as the shaft is supported by a bearing at each side.

In large marine engines cranks are built up of separate pieces, but in stationary and locomotive engines they are usually forged solid. The corners are not cut out square, but are rounded off to increase the strength.

A forged crank may be balanced by extending the sides, or webs, on the opposite side of the shaft to the crank-pin, or by bolting on cast-iron weights.

The oiling of a crank-pin presents difficulties, as a cup on the connecting-rod end cannot be refilled during a long run.

In large engines with overhung cranks (see Fig. 40), a hole is bored in the centre of the crank-pin, meeting another from the surface of the journal; a pipe leading from the former terminates in a round box opposite the centre of the shaft. This will revolve, but will not move otherwise, so that oil can be supplied through a hole in its side, and this will find its way along the pipe to the brasses.

In marine engines, a tube is carried from the crank end of the connecting-rod to the cross-head end, and a funnel, fixed to this, collects drops of oil from a stationary wick, which it touches each revolution.

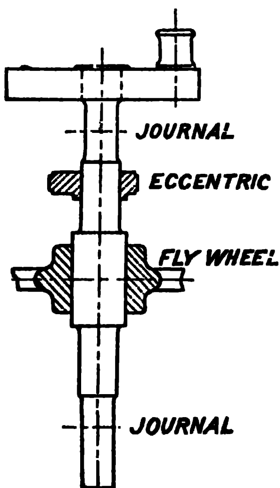


FIG. 43.—Crank-shaft of engine shown in Fig. 13.

21. The crank-shaft is made of wrought iron or steel. It rests on two bearings and is prevented from moving horizontally by collars at the sides of these bearings. The eccentric, fly-wheel, etc., are keyed to it in the same manner as the crank. The shaft is often made larger at the points where these fit, than elsewhere, to facilitate getting them into place, and to make up for the metal removed in cutting the key-ways (see Fig. 43).

22. The crank-shaft bearings are of brass, or brass lined with white metal. Either takes a good surface, and the former expands with heat more than iron, so that, when it gets hot through lack of oil, the bearing tends to open and not to grip the journal.

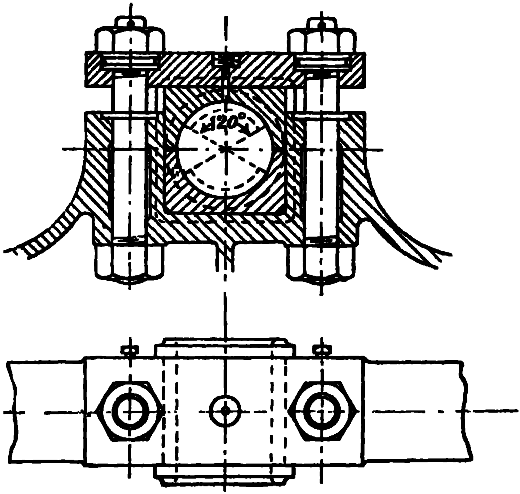


FIG. 44.—Main bearing of a marine engine.

The pressure on a bearing is made up of the force of the steam and the weight of the shaft. In vertical engines, these are both nearly vertical, so the joint in the brasses is made horizontal (see Fig. 44). They are held in the bed of the engine, and are covered with a cast-iron keep, fastened down by two bolts which withstand the pull on the crank during the up-stroke.

In horizontal engines the forces are in different directions, and their resultant is much inclined to the vertical. Therefore the joint between the brasses must also be inclined if they are to provide a proper support. This is accomplished by setting a bearing similar to that of Fig. 44 at an angle

in the frame (see Fig. 126), or as shown in Fig. 45. In the latter case the keep is screwed firmly down, and adjustment is made horizontally by two set screws, which bear on steel-plates, and are secured with lock-nuts.

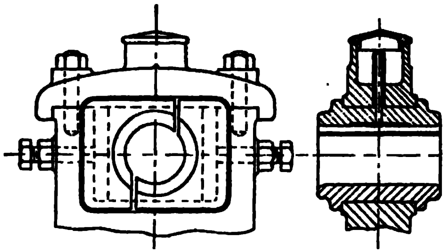


FIG. 45.—Main bearing of a horizontal portable engine.

In large horizontal engines the brasses are divided into four pieces, each of which can be adjusted separately.

Bearings often give trouble by getting hot, on account of excessive friction.

If the brasses are not accurately in line with one another, if they do not fit the shaft, or if the lubricant is not properly distributed over them, over-heating will occur.

The best results are obtained when contact is limited to the arcs, indicated by dotted lines in Fig. 44. The brasses must be carefully fitted to the shaft by hand, to insure that the pressure is evenly distributed over these arcs.

There must always be some friction, and therefore some heat generated. In ordinary working this causes a slight rise of temperature up to a point at which heat is lost by radiation as fast as it is generated by friction.

23. The Eccentric (Fig. 46).—As previously explained, this is really a short crank for giving the requisite motion to the slide-valve. In fact, a crank-arm at the end of the shaft is sometimes used for this purpose. As a general rule, however, the motion must be obtained from the centre of the shaft, and here the eccentric is the cheapest arrangement. Its full name is the "eccentric sheave," *i. e.* the sheave mounted eccentrically upon the shaft.

The eccentricity, or *throw* of the eccentric, is the distance

T (Fig. 46), between its centre and the centre of the shaft. It is half the travel of the valve, just as the throw of the crank is half the piston stroke.

The large size of the sheave entails a considerable loss in friction, but this is compensated for, to some extent, by the extended bearing-surface, over which the force required to move the valve is distributed.

This force is about $\frac{1}{10}$ of the total pressure on the back of the slide-valve.

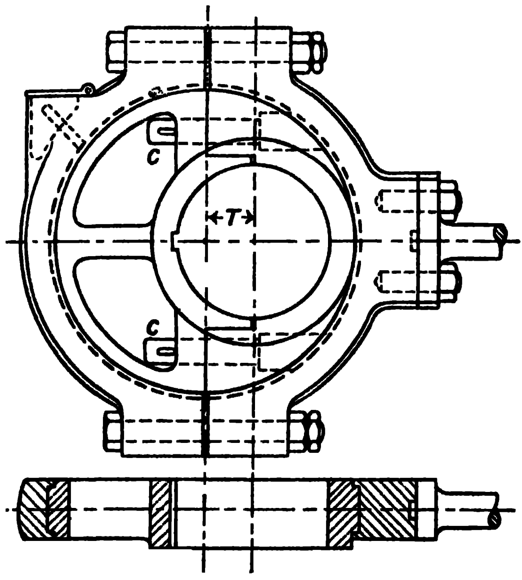


FIG. 46.—Cast-iron eccentric with brass strap.

Eccentrics are usually made of cast iron. If they cannot be slipped into place along the shaft, they must be divided. The two parts are then fastened together, in place, by cotter-bolts *C*, *C*.

The strap is of necessity in halves. It is made of brass, or of iron lined with brass.

The eccentric-rod is of flat or round wrought iron. It is connected to the valve-rod by a simple pin-joint (see Figs. 14 and 15).

We now come to the slide-valve, which is of such importance that a whole chapter must be devoted to its consideration.

Ex. 1.—The area of a slide-valve is 100 square inches, and the steam pressure upon it is 150 lbs. per square inch. Find the force required to move it.

Total pressure on valve $= 150 \times 100 = 15{,}000$ lbs.

$\therefore$ Force required to move the valve $= \frac{15{,}000}{10} = 1{,}500$ lbs.

Ex. 2.—Why is an eccentric made of cast iron, and the key, which fixes it, of steel?

The eccentric is of a form which is more easily moulded than forged, and cast iron is of sufficient strength for the purpose. The key, on the other hand, is easily forged, its size is limited, and therefore it is made of a material possessing a high resistance to shearing.

Examples IV.

1. Describe two ways of locking a nut. In what circumstances would each method be employed?

2. Sketch the large end of a marine engine connecting-rod, showing the nuts on the upper ends of the bolts, as is usual.

3. How may an overhung crank-pin be lubricated? Give a sketch.

4. Why is a connecting-rod larger at one end than the other?

5. Sketch a cast-iron balanced crank-disc, and state how it is fixed to the shaft.

6. What is the use of the balance-weight?

7. Why cannot a two-cylinder locomotive be perfectly balanced? Could a four-cylinder engine be perfectly balanced?

8. Sketch one of the bolts in Fig. 44. What is the use of the collar upon it?

9. If the total steam pressure on the engine piston, corresponding to Fig. 44, is 20,000 lbs., what should be the diameter of the steel bolts (at the bottom of the thread) according to the table of safe loads given on p. 48?

10. Sketch three views of a bearing for a small horizontal engine, and state how it is adjusted for wear.

11. What effect would wear in the bearing of Fig. 44 have upon the motion of the piston? Would wear in the bearing of Fig. 45 have the same effect?

12. Sketch an eccentric-rod, showing how it is connected to the eccentric-strap and valve-rod.

13. How is an eccentric-strap adjusted for wear?

14. Why is an eccentric usually made in two parts? How are the parts put together?

15. Make a sketch and describe the construction of an eccentric sheave and strap. Show the position of the crank-shaft through the eccentric, and indicate on your sketch the throw of the eccentric. Name the materials of which the several parts of the eccentric are made. (S. and A. 1898.)

16. Show by sketches how the piston-rod and connecting-rod are attached to the cross-head. (S. and A. 1899.)

17. Describe, with sketches, the crank-pin end of any connecting-rod. (S. and A. 1900.)

18. Sketch, in section, half the crank-shaft of a locomotive, describing the construction of the crank and driving-wheel, and showing also the two eccentric discs. (S. and A. 1900.)

NOTE.—The student should make this sketch from the actual object at the first opportunity.

CHAPTER V.

THE SLIDE-VALVE.

24. Outside and Inside Lap.—Two views of a simple slide-valve are shown in Fig. 47. It is made of cast iron, and resembles a shallow inverted box.

The valve-rod *V.R* controls its backward and forward motion, but it is allowed a small amount of freedom to adjust itself in other directions. It has guides at either side, as shown (Fig. 47), and the pressure of the steam keeps it in close contact with the port-face.

A safety guide at the back of the valve is sometimes fitted to support it when there is no steam in the steam-chest.

Figure 47 shows the valve in its mid-position; it then overlaps the steam-ports on both sides.

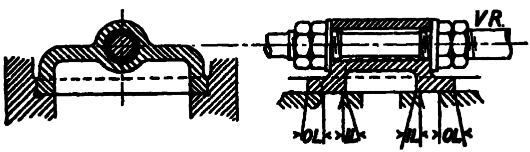


FIG. 47.—A simple slide-valve.

The "outside lap" is the name given to the distance *O L*, by which a slide-valve extends beyond the outside edge of the steam-port, when in its mid-position.

The "inside lap" is the name given to the distance *I L*, by which a slide-valve extends beyond the inside edge of the steam-port, when in its mid-position.

A few moments' thought will show the student that the amount of outside lap will affect the admission of steam to the cylinder, and the amount of inside lap will affect its

escape from the cylinder; he will be shown later in the chapter how to determine the extent of these effects.

The inside lap is often zero and is sometimes negative. In the latter case, for a short interval, both steam-ports will be open to the exhaust simultaneously.

25. Lead and Angle of Advance.—Let us suppose that the valve in Fig. 47 belongs to a horizontal engine, that the valve-rod, eccentric-rod, etc., are in place, but that the eccentric is not keyed to the shaft.

Let us place the crank horizontally with the piston at the back end of the cylinder, ready to commence its out-stroke. It was stated in § 1 that the back steam-port should now be uncovered by a small amount. This opening is called the **lead** (see Figs. 48 and 15).

The "lead" of a slide-valve is the amount by which it has uncovered the steam-port, for the admission of steam, at the commencement of either stroke of the piston.

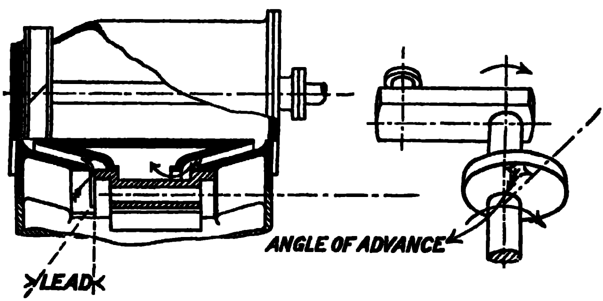


FIG. 48.—Position of slide-valve at commencement of stroke.[1]

To obtain the lead, the valve must be moved from its mid-position (Fig. 47) through a distance equal to the **outside lap, plus the lead**, and to accomplish this the eccentric must be turned round on the shaft, through the angle indicated in the right-hand part of Fig. 48. *If it*

[1] In Fig. 48 the cylinder and shaft are supposed to be below and in front of the observer, so that in looking at them his gaze is directed at an inclination of 45° to the ground.

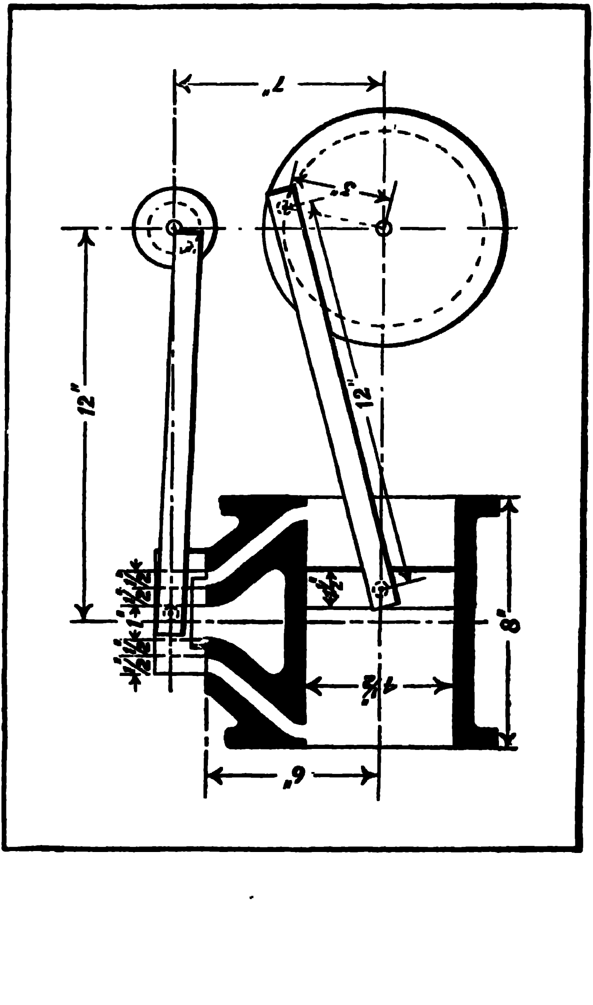


FIG. 49.—Model for studying the action of a slide-valve.

were fixed thus, the engine would work satisfactorily, the crank rotating in the direction shown, so that the latter appears to follow the eccentric.

The valve will at first travel in the same direction as the piston, and open the steam-port further. It will then begin to move in the reverse direction, and will close the port before the end of the stroke. By the time the piston has reached the front of the cylinder, the valve will have passed its mid-position again, by an amount equal to the outside lap, plus the lead, and so be correctly placed for commencing the return stroke.

The amount of lead necessary is fixed by practical experience. It is about one-eighth of the breadth of the port, and is larger in fast than in slow running engines.

Turning our attention from the valve to the eccentric, it will be noted that this was originally (*i. e.* when the valve was in its mid-position) at right angles to the crank, but it had to be "advanced" from that position through a considerable angle called "the angle of advance."

The "angle of advance" of an eccentric is the angle by which it is in advance of the crank, minus one right angle.

Fig. 15 should be referred to here, for in it the lead, and angle of advance are clearly shown, the piston being at the crank end of the cylinder.

In larger text books several geometrical methods are given for finding the correct angle of advance. The use of one of these methods enables engine builders to key the eccentric to the shaft, before the latter is put in place. All that has then to be done, after the engine is erected, is to adjust the position of the valve on the valve-rod, till the corresponding lead is obtained.

26. Experimental Study of the Action of a Slide-Valve.—Four important factors have now been defined.

The travel of the valve.
The lap " "
The lead " "
The angle of advance of the eccentric.

These are not, however, independent variables, for an alteration in any one of them involves a change in at least one of the other three. Thus, if the travel is increased, the

lead will be increased also, unless the lap is increased or the angle of advance reduced.

It is absolutely necessary for the student to study the relations of these quantities experimentally.

If a good sectional model is available, in which all four can be varied and measured accurately, so much the better. If not, he may make for himself the rough apparatus shown in Fig. 49, which will give tolerably good results. For convenience the principal dimensions are given, though of course these need not be adhered to. The larger the model can be made the better. Fig. 49 represents an engine of 6-inch stroke, with a connecting-rod 12 inches long (twice the stroke), and other parts in proportion.

The cylinder and valve-chest are drawn in section, on a sheet of paper mounted on a board. The piston-rod and valve-rod are omitted to save space, the piston and valve being coupled directly to the connecting and eccentric-rods. This does not affect their motion in the least.

All these pieces are cut out of cardboard, the journals being formed of drawing-pins inserted from below.

Since it is more convenient to have everything in one plane, the crank and eccentric are represented by discs revolving about parallel axes, instead of being fixed to the same shaft. It is necessary, therefore, to remember to treat them as if they could not rotate independently, and always to turn them through the same angle, before making a measurement. The discs must be divided by radial lines (not shown), at every 5 degrees, with a protractor; a fifth of a division, or one degree, can then be estimated by the eye. The most convenient way of numbering these lines is from 0 to 175, twice over, corresponding to the two strokes of the piston.

Three most important experiments with this model are described below. Besides showing its uses, these will impress upon the mind some fundamental ideas in connection with the slide-valve. The results are tabulated on p. 81 merely as a guide; each student should make his own table by observations on his own apparatus.

EXPERIMENT 1.—Take a valve having $\frac{3}{8}$ inch outside lap,

and $\frac{1}{8}$ inch inside lap. Insert a drawing-pin in the eccentric-disc, on the 130° line, $\frac{3}{4}$ inch from the centre. This means that the eccentric is to have an angle of advance of $130 - 90$ or 40° and the valve a travel of $1\frac{1}{2}$ inches.

Set the eccentric-disc to read 0°, the valve to uncover the back port by $\frac{1}{8}$ inch, and connect the two by an eccentric-rod of suitable length. Turn the eccentric through 180°, and see if the front port is open by $\frac{1}{8}$ inch; if it is not the length of the eccentric-rod must be adjusted till the port opening is of the same amount when either of the points marked 0° on the eccentric-disc is on the centre line; the valve will then be set correctly.

Now place the piston ready to begin an out-stroke, and mark its position on the centre line of the cylinder. Set the eccentric-disc to read 0°, with the valve partly uncovering the back port. The lead, as stated above, will be about $\frac{1}{8}$ inch.

Next turn the eccentric-disc till the valve has uncovered more of the port and closed it again. This will require a motion of 110°. Turn the crank-disc through the same angle in the same direction, to get it into its correct position, and note how far the piston has moved. The distance will be $4\frac{3}{8}$ inches, that is to say, *this valve will admit steam to the cylinder, while the piston travels $4\frac{3}{8}$ inches on an out-stroke of 6 inches.*

Rotate the eccentric again till the inside edge of the valve reaches the inside edge of the port, so that further movement will release the steam from the cylinder, and allow it to escape to the exhaust. This requires a motion of 150° from the start, and when the crank is brought up to the same angle, the piston will be found to have travelled $5\frac{11}{16}$ inches; so that *the steam expands from $4\frac{3}{8}$ inches to $5\frac{11}{16}$ inches of the stroke, and is "released" $6 - 5\frac{11}{16}$, i. e. $\frac{5}{16}$ inch before the end of the stroke.*

Finally turn the eccentric on till the escape of steam is just stopped, that is to 130° on the return stroke. The corresponding position of the piston is $1\frac{1}{4}$ inches from the end of the stroke. *From this point onwards the valve retains the steam in the cylinder*, and the piston compresses it into

the clearance space, until the port is opened to live steam near the end of the stroke.

Now repeat this whole cycle of operations for the front end of the cylinder, starting with the piston at the commencement of its in-stroke. The results appear in column 1 of the table. The first difference to be noticed is that *the piston has only moved $3\frac{3}{4}$ inches when the valve cuts off steam,* not $4\frac{3}{8}$ inches as before. The crank has turned through the same angle in each case (110°), and the difference in the position of the piston is due to the connecting-rod having become inclined, which reduces the horizontal distance between the piston and the crank-pin near the middle of the stroke. This brings the piston further from the back end of the cylinder than it otherwise would be, and so increases the portion of the out-stroke during which steam is admitted, and decreases the corresponding portion of the in-stroke.

It is obvious that a *short connecting-rod will increase this variation, and a long rod will decrease it.* The eccentric-rod, for instance, is so long in proportion to the valve-travel, that the variation due to its inclination is hardly noticeable. The difference is greatest near half-stroke, where cut-off occurs, but it also affects the release and compression.

This difference in the amount of steam admitted to the cylinder during in and out strokes is very objectionable in vertical marine engines, where the piston, cross-head, etc., have to be raised on the up-stroke, so that more steam, not less, would be required for perfectly even working. The difficulty is met by reducing the lap at the front, or lower end of the valve. This increases the lead and allows the steam supply to be cut off later on the up-stroke.

The student should try for himself the effect of reducing the lap of the valve he has just used to $\frac{5}{16}$ inch at the front end.

It will be instructive now to assume a steam pressure, say 60 lbs. per square inch absolute, and an exhaust pressure, say 15 lbs. per square inch absolute, for an engine similar to our model, and to draw diagrams, as in Fig. 22, on squared paper, to represent the action of the steam at each end of the cylinder (see Fig. 50).

The pressure will be constant up to the cut-off point. Then an expansion curve may be drawn graphically (see Fig. 21) till the release point is reached, after which the pressure is

assumed to fall uniformly till the end of the stroke. A second horizontal line represents the exhaust pressure up to the compression point. The compression curve cannot be drawn geometrically unless we assume a clearance volume, but it may be sketched in by hand, without any great error.

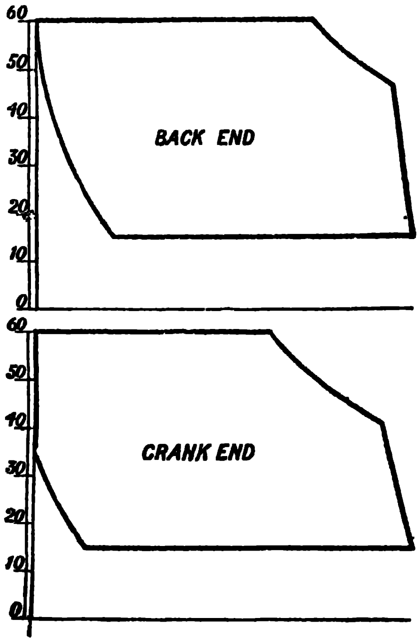


FIG. 30.—Indicator diagrams deduced from Experiment I.

These figures with their corners rounded off, represent the indicator diagrams we should expect to obtain from the engine under the conditions stated. They make it obvious that *the mean effective pressure would be greater on the out-stroke than on the in-stroke.*

The slide-valve we have used is suitable for slow-running engines. In high-speed engines, the steam would have to be released earlier. To do this, the inside lap is made less. It is, in fact, often reduced to nothing, and is sometimes a minus quantity, so that both ports are open at once to exhaust, for a short period.

27. The Effect of Varying the Lap or the Travel of a Slide-Valve.

EXPERIMENT 2.—The object of this experiment is to show the effect of increasing the lap of a valve without altering its lead.

Take a valve similar to that in experiment 1, but with an

outside lap of ½ inch, and place it with lead of ⅛ inch. Set the eccentric disc at 0°, having first marked on it a circle of ¾ inch radius. Find where the pin-hole in the eccentric-rod crosses this circle, and insert the pin there. It will be on the line marked 145°, which implies that the angle of advance must be 145° − 90°, *i. e.* 55°.

Turn the eccentric through 180° in order to check the correctness of this result, by seeing if the lead is the same at both ends.

Now repeat all the measurements made in experiment 1, and tabulate the results as in column 2 of the table.

The cut-off occurs at $3\frac{1}{16}$ inches on the out-stroke, and at 2¼ inches on the in-stroke. This shows that—*When the outside lap of a valve is increased without altering the lead, steam will be cut off earlier in the stroke.*

By reducing the lap and angle of advance, the period of admission may be *increased* till it covers nearly the whole stroke, but even when there is no lap, there will still be a small angle of advance to give the lead.

EXPERIMENT 3.—The object of this experiment is to show the effect of decreasing the travel of a slide-valve, while its lap and lead remain constant.

Put the original valve in place, with ⅛ inch lead. Mark a circle ⅝ inch radius on the eccentric-disc, and set the latter at 0°.

Find where the pin-hole in the eccentric-rod crosses this circle, and insert a drawing-pin there. It happens to come on the 145° line again, but now the slide-valve will have a travel of 1¼ inches only.

Take measurements similar to those in experiments 1 and 2, and tabulate them as in column 3 of the table.

It will be found that reducing the travel of the valve by ¼ inch has very much the same effect as increasing its lap by ⅛ inch. Thus we have now shown that—*When the travel of a slide-valve is decreased without altering its lead, steam will be cut off earlier in the stroke.*

Table of results of experiments 1, 2, *and* 3, *with the slide-valve model.*

Experiment.	1.	2.	3.
Lap, outside	⅜"	½"	⅜"
„ inside	⅛"	⅛"	⅛"
Travel	1½"	1½"	1¼"
Angle of advance	40°	55°	55°
Lead, back end	⅛"	⅛"	⅛"
„ front „	⅛"	⅛"	⅛"
Cut-off, back end	4⅜"	3 1/16"	3⅜"
„ front „	3¾"	2¼"	2⅝"
Release, back end	5 11/16"	5¼"	5¼"
„ front „	5½"	4⅞"	4⅞"
Compression, back end	1¼"	2"	2⅛"
„ front „	13/16"	1⅜"	1½"

It is an advantage from the point of view of economy, to be able to vary the period of admission of steam to the cylinder of an engine. This cannot well be done by changing the lap of the slide-valve, but it may be done by using an eccentric whose throw and angle of advance can be altered. Fig. 51 shows such a contrivance; it is held in place by a bolt passing through a disc keyed to the shaft, and can be moved at right angles to the crank. Its centre is always the same distance *D* (measured in the direction of the crank), from the centre of the shaft, and therefore the displacement of the valve at the beginning of each stroke, which determines the lead, is constant.

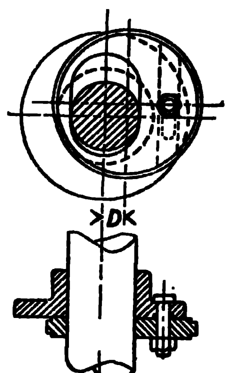


FIG. 51. — Eccentric with variable throw and angle of advance.

28. Reversing Gears.—Locomotives and marine engines require to run in both directions, and the engineer in charge must be able to reverse their motion quickly, by a single movement of a conveniently placed lever, or hand-wheel.

The simplest way to accomplish this is to fit two eccentrics on the shaft, and to employ one of them when going forwards, or ahead, and the other when going backwards, or astern. These are shown, with the crank, in Fig. 52.

The one marked *F* is used when the crank is to turn "forward," because it is in front of the crank by 90° + the angle of advance, in that direction. For the same reason the one marked *B* is used when the shaft is to run "back."

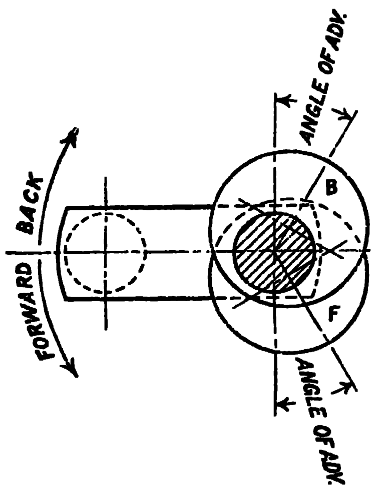


FIG. 52.—Diagram of "forward" and "backward" eccentrics.

The two eccentric-rods are coupled to opposite ends of a slotted link curved into a circular arc of which the shaft is the centre (see Fig. 53); a block of metal slides in the link, and to this block the forked end of the valve-rod is attached by a pin. The link is hung from a bell-crank lever, by moving which either eccentric-rod can be brought into line with the valve-rod. The latter will, of course, take its motion from that eccentric-rod which is opposite to it, while the other rod merely rocks the link to and fro.

This reversing gear was invented by George Stephenson for the locomotives which he designed, and it is therefore known as "Stephenson's Link Motion."

Here again the reader is strongly advised to study the action of the mechanism with a good-sized model. He will then be able to see, by experiment, (1) how the lead varies as the gear is moved over from "forward" to "backward"; (2) how this variation is affected by crossing the eccentric-rods before coupling them to the "link."

Fig. 53 shows the motion in **mid gear**, as it is called. The thick dotted lines indicate the position of the parts when it is in **full-forward gear.**

Even at mid gear the valve moves sufficiently to uncover the ports, but as it opens these for as long a time before as after the commencement of each stroke, the piston is

checked as much as it is driven by the steam. This opening is, in fact, the lead, which is shown, by the dotted centre lines (Fig. 53), to increase slightly, as the "motion" is moved over from full gear to mid gear.

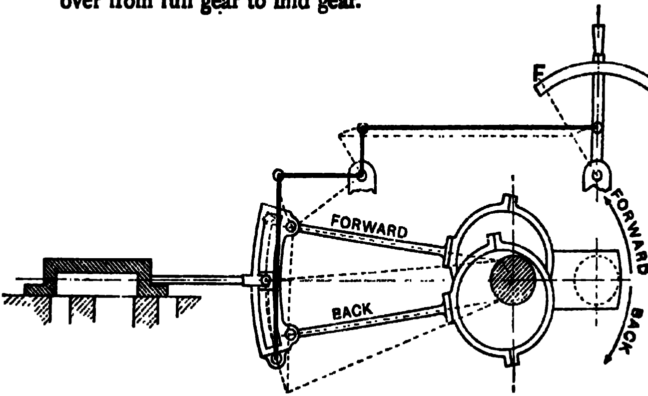


FIG. 53.—Stephenson's "link-motion" reversing gear.

At full gear the travel of the slide-valve is obviously twice the throw of the eccentric. If the slotted link is held in some intermediate position between full gear and mid gear, the effect will be to reduce this travel, without (as shown above) greatly altering the lead. Now we have seen by experiment 3 that such a process causes steam to be cut off earlier in the stroke, and so reduces the mean pressure on the piston. This "linking up," as it is called, forms, therefore, a very convenient and economical way of regulating the power of an engine. It is, in fact, constantly used by locomotive drivers.

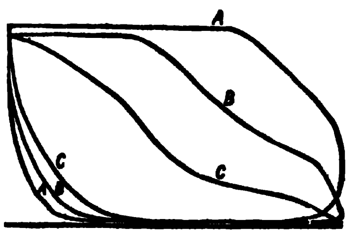


FIG. 54.

Fig. 54 shows three indicator diagrams which were taken on the Great Western Railway Company's

locomotive "Great Britain" at nearly the same boiler pressure. *A* was taken at full gear, *B* at ½ full gear, and *C* at ⅛ full gear. These illustrate the variation in cut-off, release, compression, and mean pressure very clearly.

The serious extent to which the steam is wire-drawn in *C* should be noted.

29. Indications of Incorrect Valve Setting.—Before leaving the consideration of slide-valves, it will be well to

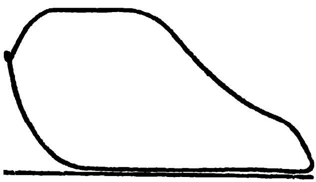


Fig. 55.—Indicator diagram showing insufficient lead.

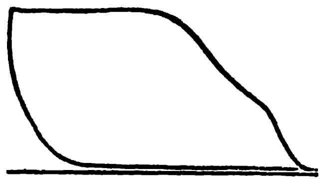


Fig. 56.—Indicator diagram showing premature release.

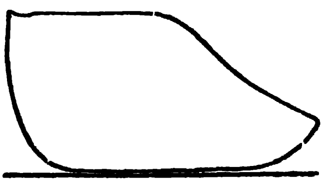


Fig. 57.—Indicator diagram showing late release.

Fig. 58.—Indicator diagram showing too great a ratio of expansion.

notice some effects which follow if they are badly set. These effects are made evident by the use of the indicator; for instance, if a diagram similar to Fig. 55 (*i. e.* with a small loop at the admission end) is obtained from an engine, it shows that the lead is insufficient. If the pressure falls to its exhaust value before the end of the stroke (see Fig. 56), release occurs too early. If, on the other hand, the "toe" of the diagram is turned up (see Fig. 57) release occurs too late.

When steam is cut off too soon, it may be expanded till

its pressure falls below that in the exhaust-pipe. A looped diagram, like Fig. 58, will then be obtained.

All these four cases should be compared with the diagrams in Fig. 54, the forms of which indicate a properly adjusted valve.

EXAMPLES V.

1. Draw to scale one sectional view of a slide-valve from the following dimensions—

Outside lap = 1″.
Inside lap = 0.
Breadth of steam-ports = 1″.
Breadth of exhaust-port = 1½″.
Thickness of metal between ports = ¾″.

2. If the travel of the above valve is 3½ inches, what is the greatest breadth of the steam-port it will uncover?

3. The throw of an eccentric is 4 inches, and its angle of advance is 30°. Find, by a scale drawing, the distance of the valve from its mean position at the beginning of each stroke.

4. What must be the lap of the above valve if its lead is ¼ inch?

5. Sketch a slide-valve with no lap but a small amount of lead, showing its position at the commencement of the stroke.

6 Make an experiment similar to experiment 1, with a valve having no lap and ⅛ inch lead. Draw up the results in a table.

7. Assuming the initial and back pressure shown in Fig. 50, draw indicator diagrams for an engine with its valve set as in experiment 3.

8. Find the mean effective pressure represented by each of these diagrams.

9. Find the mean effective pressure represented by the diagrams in Fig. 50.

10. The angle of advance of an eccentric is 45°. The valve which it drives has an outside lap equal to half the breadth of the steam-port, and a travel of twice the breadth of the steam-port. Find with a model its lead, and when it will cut off steam, assuming a connecting-rod twice the stroke in length.

11. The connecting-rod of an engine is 2½ times the stroke in length. Find graphically (*a*) the position of the crank when the piston is at half-stroke, (*b*) the position of the piston when the crank is 90° from a dead point.

12. The length of the connecting-rods is three times the stroke in many locomotives, and only twice the stroke in most marine engines. In the

former case, the lap of the valves is made the same at both ends; in the latter case, it is made less at the lower end. Give two reasons for this difference.

13. Sketch three views of an eccentric whose travel can be varied. Why is it not made so that the travel can be reduced to nothing?

14. A portable engine is used for thrashing in the autumn and to drive a circular saw in the winter. It has to run in opposite directions for these jobs. Could this be accomplished by fitting it with the eccentric shown in Fig. 51?

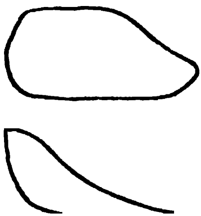


FIG. 59.

15. Make sketches of a Stephenson's link-motion reversing gear, (*a*) in mid gear, (*b*) in forward gear, (*c*) in back gear.

16. Comment on the indicator diagrams in Fig. 59.

17. Describe and sketch a slide-valve, describe how it distributes the steam, and how it is worked.

What is meant by the terms lap, half travel, inside lap, and advance? (S. and A. 1898.)

18. If steam is cut off both on the down and up strokes of a vertical engine (the crank being below the cylinder) when the crank makes an angle of 70° with a dead point, show that this means a later cut-off in the down-stroke than in the up-stroke. Is this a good or a bad result? (S. and A. 1900.)

CHAPTER VI.

THE FLY-WHEEL AND GOVERNOR.

30. Variation of Crank Effort.—In Chapter I. it was pointed out that in each revolution of a single cylinder-engine there are two dead points at which the pressure of the steam on the piston has no power to rotate the shaft. From these dead points the effect of the steam pressure increases during the first part of each stroke, decreases again during the latter part, and is greatest when the connecting-rod and crank are at right angles.

The student may prove this statement experimentally with the simple model shown in Fig. 60.

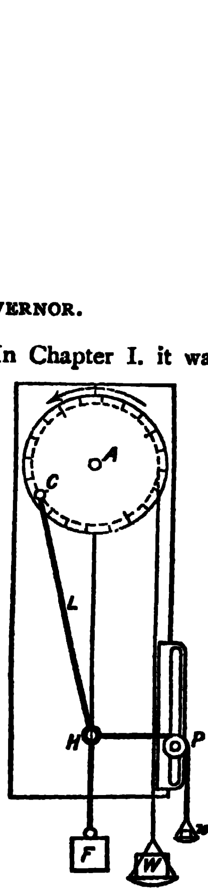


FIG. 60.

A is a grooved disc turning on a pivot in an upright board; *C* is a peg fixed in it, at the same radius as the bottom of the groove; a string *L* connects *C* with the ring *H*, which supports a weight *F*. A horizontal cord, which is also attached to *H*, passes over an adjustable pulley *P*, and carries the small weight *w*. Round the disc *A* is wound a third cord, with a weight *W* in a scale-pan at its lower end. The circumference of *A* is divided into (say 20) equal parts,

starting from *C*, as shown; and a vertical centre line is drawn on the board.

It is easy to see that the apparatus, thus arranged, represents the mechanism of the steam-engine. *A* is the crank-disc, *C* the crank-pin, *L* the connecting-rod, and *H* the cross-head. In the position shown two-thirds of the down-stroke have been completed. When the weights are arranged to balance, *F* corresponds to the total effective steam pressure on the piston, *W* to the effect this would have in rotating the crank (or the *crank effort* as it is called), and *w* the horizontal force required to keep the cross-head moving in a straight line, *i.e.* the pressure of the guide-bars.

EXPERIMENT.—To determine how the *crank effort* varies during one stroke of an engine working without expansion or compression, *i.e.* of an engine in which the effective pressure is constant.

Attach any convenient weight *F* (say 10 lbs.) to represent the constant steam pressure. Adjust *W* till the disc rests with the first division from *C* opposite the centre line. Lower the pulley *P* till the cord passing over it is horizontal, and increase *w* till *H* hangs in front of the centre line. Readjust *W* if necessary, and note its value. Repeat these operations at each succeeding division till the stroke is completed, noting the value of *W* each time. Great care is necessary in some positions, where a slight displacement of the crank will entirely upset the balance.

The results are best recorded on squared paper (see Fig. 61). The equidistant points 0, 1, 2, etc. are marked off, along a horizontal base line, to represent the equal divisions on the crank circle, and from each point an ordinate is measured proportional to the corresponding value of *W*. Thus *db* represents the value of *W* when the crank has rotated through 4 divisions, on a scale of 10 lbs. to the inch.

A curve drawn through the heads of these ordinates, shows graphically the crank effort for *all* positions of the mechanism throughout one complete stroke.

The reader will notice that W is nearly always less than F; this may surprise him unless he remembers that the *work* done on the piston must equal that done on the crank.

Now, work done on piston during each stroke $= F \times$ stroke.

$$\left.\begin{array}{l}\text{Work done on crank-pin}\\ \text{during each stroke}\end{array}\right\} = \text{mean value of } W \times \frac{3\cdot14 \times \text{stroke}}{2}$$

$$\therefore F \times \text{stroke} = \text{mean value of } W \times \frac{3\cdot14}{2} \times \text{stroke}.$$

$$\therefore \text{mean value of } W = \cdot636\, F.$$

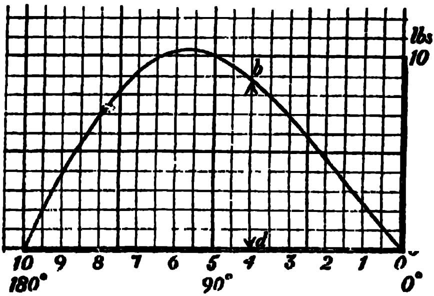


FIG. 61.—Curve of crank effort when the pressure on the piston is constant.

The simplest possible distribution of force has been chosen for this experiment, but the model may just as easily be used to illustrate a more complicated case, where the effective pressure is not constant, by changing the weight F for each point.

Since the pressure is always greatest at the beginning of the stroke, a more peaked curve will be obtained in the latter case; for instance, Fig. 62 shows the variation of crank effort during two consecutive strokes of an actual engine; to draw it, the correct value of F for each position of the crank was determined from a pair of indicator diagrams.

It was pointed out in § 17 that, at the beginning of each stroke, part of the force on the piston is absorbed in *accelerating* the latter. At the end of the stroke the piston suffers a negative acceleration (or retardation), and therefore exerts, of itself, a corresponding force on the crank, while its velocity is being checked. Allowance has been made for this effect in Fig. 62; it alters the *form* of the curve, but not the average value of the crank effort.

31. The Function of the Fly-wheel.—An engine usually has to work against a constant resistance to motion, like the pull of a driving-belt.

This resistance is equivalent to a steady force at the crank-pin (represented by the dotted line *ABCD*, Fig. 62) opposing its motion. The crank effort is sometimes greater than the latter and sometimes less, but its average value is equal to it.

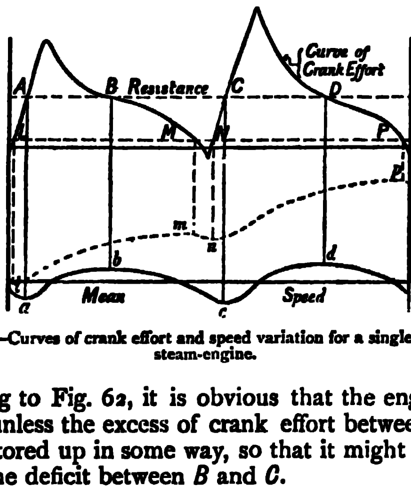


FIG. 62.—Curves of crank effort and speed variation for a single-cylinder steam-engine.

Referring to Fig. 62, it is obvious that the engine would stop at *B* unless the excess of crank effort between *A* and *B* could be stored up in some way, so that it might be used to make up the deficit between *B* and *C*.

A fly-wheel of large diameter, with a heavy rim, forms a simple means of doing this.

The student's attention has already been called to the fact, that force is required to increase the velocity of a heavy body, and that a moving weight will exert a corresponding force on anything that tends to bring it to rest. This is true whether the movement is in a straight line (as in the case of a piston) or in a circle (as in the case of the rim of a wheel); therefore a fly-wheel, on account of the mass of metal which it contains, will store up the effect of a force, or give it out, according as the velocity of that mass is increased or decreased.

This power is well illustrated in those little toys which are driven by a heavy disc set in motion, like a spinning-top, by pulling a string wound round its spindle. Here the effect of a large force acting for a few seconds on the string is stored in the revolving disc and gradually given out again in keeping the model moving for a minute or more.

In the case of the steam-engine fly-wheel the same thing happens in a smaller degree. When the crank effort exceeds the resistance, as between *A* and *B* (Fig. 62), the excess of force makes the fly-wheel move faster. When the resistance exceeds the crank effort, as between *B* and *C*, the fly-wheel has to supply the deficit of force and is "slowed down" in consequence. From *C* to *D* it is accelerated again, and so on. The variation of its speed about the mean, during each revolution, is shown by the lower continuous curve.

Its velocity increases from *a* to *b* and from *c* to *d*, where the crank effort is in excess, and decreases from *b* to *c*, where the resistance is in excess. The larger and heavier the fly-wheel, the less will be this variation in speed. The weight is naturally concentrated, as far as possible, in the fastest moving part, viz. the rim. The size of the wheel is limited by the fact that the centrifugal force will be greater than ordinary cast iron can stand if the circumferential velocity exceeds 80 feet per second or about a mile a minute.

Large wheels are made in two or more pieces, for they are then both more easily cast and fitted into place, but the strength of the wheel is considerably reduced.

When an engine has two cylinders, they may be arranged so that one is giving its maximum crank effort while the other is at a dead point. This is done in locomotives, and here the whole engine and train take a share in steadying the speed; they only differ from a fly-wheel in moving in a straight line instead of revolving. In marine engines three or four cranks set at suitable angles are used, which together give a very uniform effort.

The work done in changing the velocity of a body may be calculated as follows—

Let W = the weight of the body.
P = the force acting upon it.
f = its acceleration.
V_1 and V_2 = its velocity at the beginning and end of a short period of time t, during which the force F may be considered constant.
S = the space traversed by the body in the time t.

Then the work done on the body in time t

$$= P.S$$
$$= \frac{W}{32} f.S \text{ (see page 60)}$$
$$\text{but } f = \frac{V_2 - V_1}{t}$$
$$\text{and } s = \frac{V_2 + V_1}{2} t$$
$$\therefore P.S = \frac{W}{32} \frac{(V_2 - V_1)}{t} \frac{(V_2 + V_1)}{2} t$$
$$\therefore P.S = \frac{W}{32} \frac{(V_2^2 - V_1^2)}{2}.$$

Ex. 1.—A fly-wheel 5 ft. 3 ins. in diameter has a rim weighing 1,000 lbs. Find the number of foot pounds of work required to set this rotating 120 times per minute.

$$W = 1{,}000 \text{ lbs.}$$
$$V_1 = 0$$
$$V_2 = \frac{120}{60} \times \frac{63}{12} \times \frac{22}{7}$$
$$= 33 \text{ feet per sec.}$$
$$\therefore \text{work required} = \frac{W V_2^2}{32 \times 2}$$
$$= \frac{1{,}000 \times 33 \times 33}{32 \times 2}$$
$$= 17{,}016 \text{ ft. lbs.}$$

32. The Function of the Governor.—So far it has been assumed that an engine works against a constant resistance, and, even on this assumption, it has been shown that there will be a small periodic variation in its speed.

Suppose now that the resistance suddenly changes. If, to take an extreme case, the driving-belt were to break, only the friction of the bearings, piston, etc., would have to be overcome. This resistance is represented by the dotted line *LMNP*, Fig. 62. It is evident that the speed of the fly-wheel would be increased more than decreased in each revolution, so that the average speed would steadily rise (as shown by the dotted curve *lmnp*), unless the crank effort or—what comes to the same thing—the mean effective pressure on the piston were reduced. The engine man might, if he were at hand, partially close the stop-valve so that the steam would be wire-drawn by it and have its initial pressure lowered; but a more reliable and satisfactory arrangement is to make the engine perform the operation automatically. For this purpose a *governor* and *throttle-valve* are used.

A simple type of belt-driven governor, suitable for a small engine, has already been described on page 15. Fig. 63 shows the throttle-valve and governor of a large, vertical, high-speed engine.

The throttle-valve appears in section. It is cylindrical, and it moves over steam-ports formed in a cylindrical casting which projects into the valve casing. It is raised and lowered by the vertical spindle *V*. The paths by which steam can normally pass from the steam-pipe to the engine are indicated by arrows.

The governor consists of two weights *W*, *W*, attached, by pin joints, to a bracket mounted upon the end of the crank-shaft. The weights are held together by strong springs, but, when the speed of the shaft exceeds a certain limit, their centrifugal tendency overcomes the pull of these springs, and they move apart, displacing, as they do so, the horizontal spindle *S*, through the arms *A*. This spindle, in its turn, actuates the bell-crank lever *L*, which draws down the vertical spindle *V*, and lowers the throttle-valve *TV*, partially closing the steam-ports, so that the pressure at which steam reaches the engine is reduced by wire-drawing.

A further increase in speed will cause a further motion of the weights and valve, and consequently further wire-drawing, till the balance between the effective pressure on

the engine pistons and the resistance to be overcome is fully restored.

It is obvious from this that an engine will run rather faster under a light than under a heavy load.

The average speed at which this governor allows the engine to work can be slightly varied at any time, even while running, by adjusting the hand-wheel *H*, which turns on a screwed portion of the spindle *V*, and alters the compression of the auxiliary spring *AS*, bearing upon the frame.

It is more important that a throttle-valve should move without friction and that the steam pressure upon it should neither tend to open nor to close it than that it should be absolutely steam tight when shut. It should close by its own weight if the mechanism which actuates it breaks down. Friction in the moving parts of a governor should also be avoided by making the controlling springs act directly upon the weights instead of transmitting their force through intermediate links and joints. *The greater the friction that has to be overcome the greater the change of speed which must take place before the governor can readjust itself.*

33. The Two Systems of Governing.—The throttling system of governing is the simplest, but a different and, under ordinary conditions, more economical method is frequently employed. In this method the period of admission of steam to the cylinder is reduced instead of its initial pressure. The simplest way in which this can be done is to attach two spring-controlled weights to the crank-shaft, and to connect them with a loose eccentric similar to Fig. 51; so that, when the speed enables them to overcome the pull of the springs and move outwards, they reduce the throw of the eccentric and cause the slide-valve which it actuates, to cut off steam earlier, as explained in Chapter V. A governor of this form is called a *shaft-governor*.

The application of this means of controlling the power developed to engines with more complicated valve-gears will be referred to subsequently.

The relative advantages of the two systems of governing are plainly shown in Fig. 65; ordinates to the straight line *A*

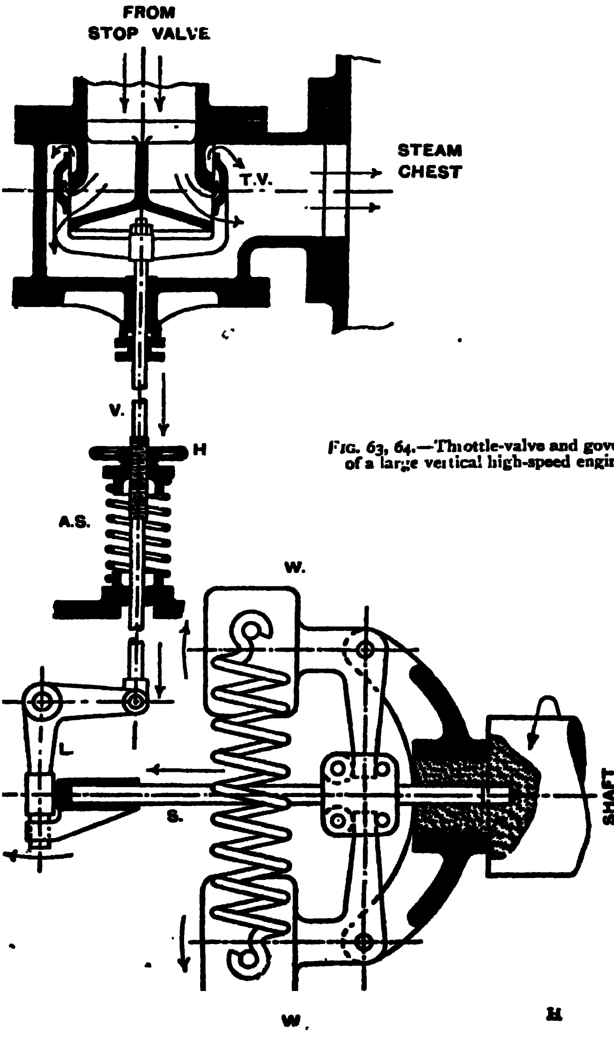


FIG. 63, 64.—Throttle-valve and governor of a large vertical high-speed engine.

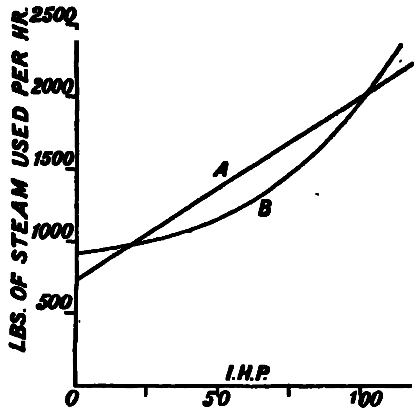


FIG. 65.

represent the pounds of steam per hour used by an engine at various powers when it is governed by varying the initial pressure; and ordinates to the curved line *B* represent pounds of steam used per hour, at the same powers by the same engine when governed by varying the ratio of expansion in its cylinder.

The forms of these lines were first established by the experiments of the late Mr. Willans, and the simple ruie, expressed graphically by the straight line *A* (Fig. 65), and in words by the statement that *the total weight of steam required by an engine working with a constant ratio of expansion is proportional to the horse-power developed plus a constant quantity*, is now known as *Willans law*.

The constant is the horse-power represented by the distance between the points at which the vertical through *O* (Fig. 65) and the line *A* produced cut the base.

34. Governing of Engines in General.—It was shown above that a governor allows some decrease of speed in an engine between light load and full load. This variation

may be made very small, but it must always be greater than the change of velocity during each revolution due to the varying crank effort; otherwise the latter would cause the throttle-valve to close and open, or the travel of the slide-valve to be greatly altered, during each stroke, and this would entirely upset steady running.

The reader should if possible count the revolutions of an engine at light load and full load. He will then see for himself what variation of speed is allowed by its governor. He should also note how the position of the balls or weights changes with the load.

Accurate governing is most important in factory and in electric-lighting engines. In locomotives the driver is of necessity always on the look-out; and, as the speed cannot change suddenly, owing to the enormous mass of the engine and train, he has time to adjust the crank effort to balance the resistance by hand, either with the stop-valve, or by "linking up" the reversing gear; an automatic governor is therefore unnecessary.

Marine engines are best controlled by hand when a vessel is entering or leaving port; at other times their speed is regulated by the boiler pressure alone. The resistance of the screw will keep them from running too fast, so long as the latter is immersed. A form of governor which comes into action only when the speed is dangerously high, is, however, occasionally fitted to these engines with a view to preventing accidents similar to that which occurred on board the twin-screw steamer *City of Paris*, some years ago. Here the port propeller shaft broke, and the port engines, having practically no resistance to overcome, acquired an enormous velocity before steam could be shut off; in consequence some of their moving parts broke loose, and striking the starboard engines damaged the latter so seriously that the ship was left helpless.

Ex. 2.—Distinguish between the functions of the *fly-wheel* and *governor*.

The fly-wheel, on account of its mass and velocity, carries an engine over its dead points and tends to reduce *periodic* variations of speed. It forms a reservoir of energy in which the work done by the steam on the piston may be temporarily stored, but it cannot alter the total

amount of that work. The governor, on the other hand, *does* alter the total amount of that work, and adjusts it so that an almost constant number of revolutions is maintained whatever be the power which the engine is called upon to develop.

EXAMPLES VI.

1. Draw the combined crank-effort curve of an engine which has two cranks set at right angles, if the turning force on each varies as shown in Fig. 62.

2. Which of the following engines, working at the same power and speed, would probably require the largest fly-wheel?—

   (*a*) A single-cylinder engine in which steam is admitted throughout the stroke.

   (*b*) A double-cylinder engine, with cranks at right angles, in which steam is cut off at quarter stroke.

   (*c*) A double-cylinder engine similar to the above, but with its cranks set opposite to each other.

3. Why are fly-wheels not fitted to marine engines? Give two reasons.

4. Why is a fly-wheel fitted to a traction engine, but not to a railway engine?

5. What are the advantages and disadvantages of making fly-wheels in halves?

6. Sketch the joint in the rim of any fly-wheel made in sections to which you have access.

7. An engine is to run at 200 revolutions per minute. Find the diameter of the largest fly-wheel that can safely be fitted to it.

8. A locomotive weighs 60 tons, calculate the total work stored in it when its velocity is (*a*) 30 miles per hour, (*b*) 60 miles per hour.
Note.—60 miles per hour = 88 feet per second.

9. Sketch and describe a throttle-valve.

10. Sketch the governor shown in Fig. 63 as it appears when the throttle-valve is closed.

11. Why can engines having heavy fly-wheels be fitted with more delicate governors than those having light fly-wheels?

12. Why do we regulate an engine with both fly-wheel and governor? Explain clearly how each affects the regulation. (S. and A. 1900.)

13. The load on an engine in an electric lighting station is 20 kilowatts from 6 p.m. to 8 p.m. It then increases to 250 kilowatts, and remains steady till 11 p.m. when it gradually falls again, being 150 kilowatts at 11.30 p.m., and 50 kilowatts at midnight. Describe fully the action of the governor throughout this period.
Note.—1 kilowatt = 1·34 horse-power.

CHAPTER VII.

THE BOILER.

35. The Production of Steam and Qualifications of a Good Boiler.—Now that the reader has acquired some clear ideas about the action of steam in driving a simple engine, it is time for him to turn his attention to its production. It is produced in a boiler, which consists, essentially, of a closed vessel, heated by a furnace where some combustible material, such as coal, coke, oil, or wood, is burnt. Into this vessel a continuous stream of cold water is pumped, which is vaporized and drawn off as steam, through a pipe leading to the engine. The boiler is, therefore, an apparatus for collecting the heat produced in a furnace, and transferring it to a stream of water.

Some boilers contain a large quantity of water, which forms a reserve, in case the supply is stopped, or the demand for steam suddenly increases; others, such as those used on motor-cars, hold no reserve, and consequently require very careful attention.

No boiler will work satisfactorily, or produce a maximum amount of steam for a minimum supply of fuel, unless it satisfies the following conditions—

(*a*) The heating surface, or the surface on which the heated gases from the furnace play, must be large.

(*b*) All parts of the boiler subjected to the heat of the furnace must be covered with water.

(*c*) There must be a thorough circulation of water throughout the boiler.

(*d*) The steam produced must be able to rise freely to the

top of the boiler, and must be allowed ample space to separate itself from the water before it is drawn off.

(*e*) All parts of the boiler must be accessible for periodic examination, so that any corrosion may be noted, and small leaks stopped as soon as they appear.

Roughly speaking, one pound of coal will convert eight pounds of water into steam, under average working conditions. Now in a factory boiler of the Cornish or Lancashire type (which will be described shortly), it is found best to burn about 12 pounds of coal per square foot of fire-grate area per hour. In marine and locomotive boilers, where the heating surface is much larger in proportion to the size of the furnace, 30 to 50 pounds may be burnt, per square foot, per hour, with equally good results.

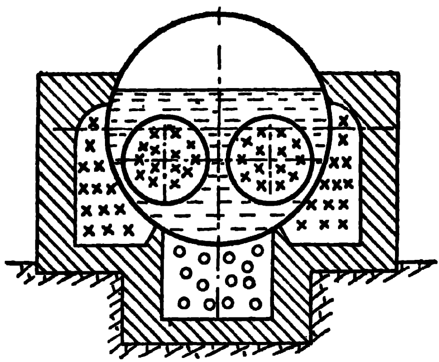


Fig. 66.—Cross-section of a Lancashire boiler.

The grate area is, therefore, a measure of the steam-producing capacity of a boiler. Thus, for example, if a marine boiler is required to supply 10,000 pounds of steam per hour, the total area of its furnace grates must be

$$\frac{10,000}{8 \times 30} \text{ or 42 square feet, nearly.}$$

1 Sq ft of the [illegible] 10 Sq ft grate area

36. The Lancashire and Cornish Types of Boiler.—The commonest form of fixed boiler in this country is the Lancashire boiler. In it the furnaces are placed within two tubes passing horizontally through a larger cylinder containing water. This boiler was first introduced in Lancashire (hence its name) in 1844, as an improvement on the single-tubed Cornish boiler, invented by Trevithick early last century. It was claimed that, by having two fires stoked alternately, a very even supply of steam could be maintained, and that two tubes allowed a freer circulation of water than one.

In both designs the hot gases issuing from the furnace

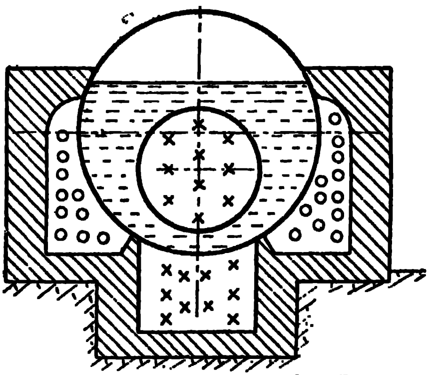


FIG. 67.—Cross-section of a Cornish boiler.

tubes are made to pass along a series of flues surrounding the lower part of the shell, in order that they may supply further heat to the water through this, before reaching the chimney. In Lancashire boilers it is usual for them to enter the lower flue first, and to return along the two upper ones. In Cornish boilers this plan is sometimes reversed, because in that type steam cannot rise so readily from the bottom as from the sides.

Figs. 66 and 67 show both arrangements. In these the uses are represented by crosses, when passing from front to ck, and by circles, when travelling in the opposite direction.

Fig. 68 shows an improved form of the Cornish boiler, known as the "German Cornish boiler," recently introduced abroad with very good results.

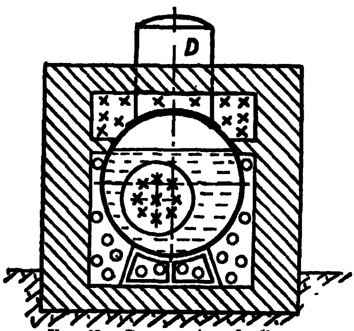


FIG. 68.- Cross-section of a German Cornish boiler.

The furnace tube is at one side, to insure good circulation. The shell rests on cast-iron seats, and is entirely enclosed with brickwork, the steam being drawn off from a dome *D* on the top.

37. Construction of the Shell of a Lancashire Boiler. — Fig. 69 is a longitudinal section of a Lancashire boiler designed for a working pressure of 80 pounds per square inch. The area of each of its grates is 16½ square feet, so that it might reasonably be expected to supply 8 × 12 × 33 or 3,168 pounds of steam per hour, which would be sufficient to drive a 100 horse-power non-condensing engine.

The shell is 28 feet long, and 7 feet 6 inches in diameter. It consists of 9 mild steel plates, ½ inch thick, rolled into a circular form, with the ends overlapped and riveted together. These fit over one another alternately, as shown. All the joints are made steam-tight after riveting by driving the inner edge of each plate inwards into close contact with the other plate. This is done with a caulking tool, resembling a blunt chisel, as shown in Fig. 70.

Fig. 71 indicates the arrangement of the rivets where three edges meet. There are two rows in the longitudinal seam, for, as will be explained later, this has to withstand more than twice the force on the circumferential seam.

There are three steel brackets riveted to the top of the shell for attaching two safety valves and a stop valve opening into the steam-pipe. There is a fourth bracket at the bottom for the blow-off cock, by which the boiler is emptied.

A manhole is provided large enough to admit a man into

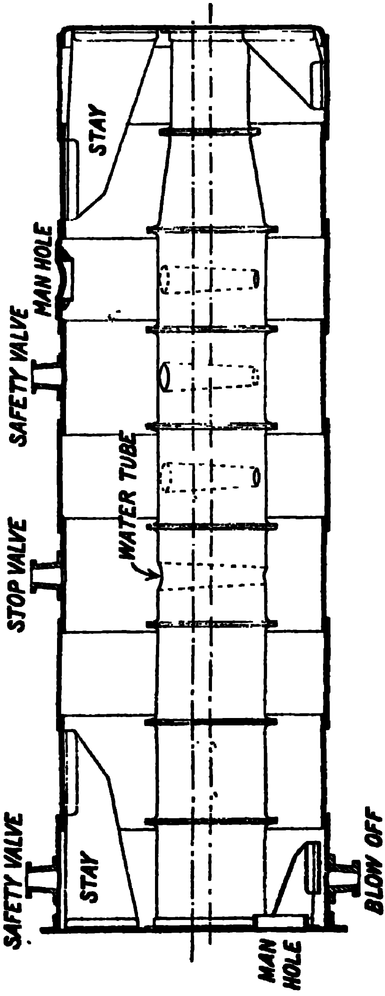


Fig 69.—Lancashire boiler 28′ 0″ × 7′ 6″. Working pressure 80 lbs. per sq. inch.

the boiler for cleaning or repairing it. The cover for this is shown in Fig. 72. It is dished to enable it to withstand the pressure upon it, and it is held in place by two bolts passing through movable cross-bars.

The metal cut-out of the shell is compensated for by riveting broad rings round the aperture. If this were not done the plate would be seriously weakened.

Each end plate is in one piece, $\frac{5}{8}$ inch thick. The total pressure on these is very great. It is calculated as follows—

Area of plate

$$= \text{cross-section of shell} - \text{cross-section of tubes}$$
$$= \cdot 7854 \times (7\tfrac{1}{2})^2 - \cdot 7854 \times 3^2 \times 2, \text{ sq. ft.}$$
$$= \cdot 7854 \left(\frac{225}{4} - 18\right), \text{ sq. ft.}$$

$\therefore$ Total pressure on plate

$$= \frac{80 \times 144}{2240} \times \cdot 7854 \left(\frac{225}{4} - 18\right) \text{ tons}$$
$$= 154 \text{ tons.}$$

To support each plate against this force, seven gusset stays, secured by angle irons, are inserted, as shown in Figs. 69 and 73. In addition to these, two or more longitudinal stays, in the form of round bars, are often passed right through the boiler from end to end, and made fast with double nuts.

When the fires are first lighted the tubes become hotter above than below. They therefore expand more at the top than at the bottom, and tend to bend upwards. Unless the end plates can spring a little to allow of this motion, there will be a great stress on the joints, which may cause a leakage.

To insure sufficient freedom a clear breadth of several inches is left all round the ring of rivets securing the tubes, and, to provide this, the front end plate is attached to the shell by an external angle ring.

At the back the tubes are of smaller diameter, so that a joint made by flanging the back end plate is permissible, and this has the advantage over the other form, of being less liable to damage from the heat of the flames.

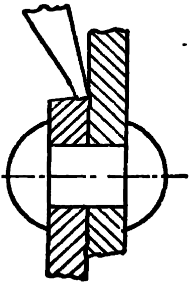


FIG. 70.

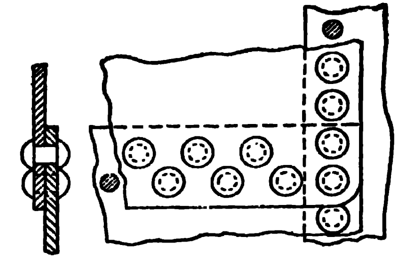


FIG. 71.

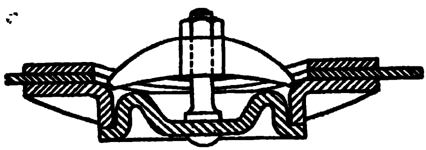


FIG. 72.—McNeil's patent manhole door.

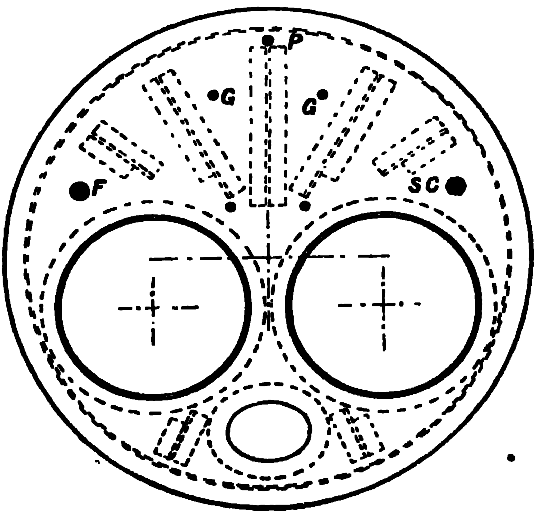


FIG. 73.—Front end plate of a Lancashire boiler.

There is a second manhole near the bottom of the front plate for cleaning out the boiler below the tubes.

The position of the following mountings is indicated in Fig. 73—

At *F* a feed-water check-valve through which the water supply is pumped, and which prevents any flow in the reverse direction.

At *SC* a scum cock for blowing off the upper surface of the water on which scum collects.

At *G*, *G* two gauge-glasses for showing the water-level.

At *P* a steam pressure gauge.

All these will be fully described in the next chapter.

38. The Furnace Tubes and Fire Grate.—The furnace tubes (Figs. 67 and 73) are built up of 9 sections. Seven of these are 3 feet in diameter, the 8th is tapered, and the last is 2 feet 6 inches in diameter. The sections have their longitudinal joints welded. They are $\frac{3}{8}$ inch thick. Their ends are flanged outwards in a broad curve and riveted together, with a stiffening ring between them (see Fig. 74).

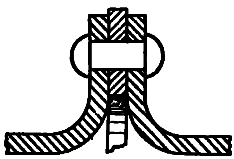


FIG. 74.—Furnace tube collapse ring.

This form of joint protects the rivets from the heat of the flames, and provides a small amount of flexibility, to compensate for unequal heating; its main object, however, is to prevent the tube collapsing under the external steam pressure.

A cylindrical vessel subject to a high *internal* pressure will tend to return to its cylindrical form after being distorted. A cycle tire is a good example of this fact; but, when the pressure acts *externally*, the case is quite different, a slight deformation tends to increase rapidly, till the original form of the vessel is completely changed.

EXPERIMENT.—Take a piece of stout rubber gas-pipe, close one end, blow into the other. It will still remain circular. Next exhaust the pipe of air so that the external pressure upon it becomes the greater. It will at once collapse.

The cross-tubes, or water-tubes, fitted into each flue give these additional support. They also considerably increase the heating surface of the boiler, and improve the circulation. One is vertical and the other three are inclined at 30° to the vertical. Their ends are flanged, and they are tapered so that the lower end can be inserted through the upper hole.

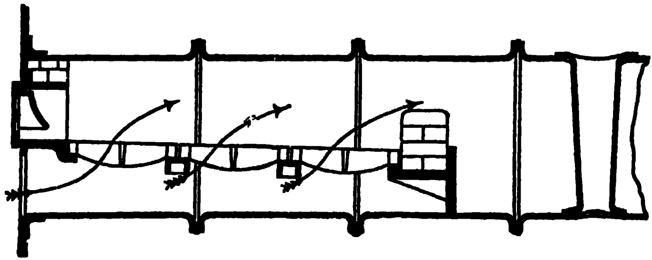


FIG. 75.—Fire-bars and furnace tube of a Lancashire boiler.

The furnace (see Fig. 75) is 6 feet long. If it were much longer than this, the stoker could not keep the fire in good condition at the back. It is divided off from the rest of the flue by a fire-brick bridge which rests on a cast-iron frame closing in the ash-pit. The fire-bars are in three lengths. They are ½ inch broad at the top, and there is an air space, ⅜ inch broad, between them. They rest on cross-bearers, bedding on the sides of the tube, and kept in position by longitudinal tie-rods. The back of the grate is lower than the front to facilitate stoking. The furnace front is closed in by a cast-iron frame, and a hinged door, fitted with a regulating valve for admitting air above the fires when desired. If this is closed, the whole air supply must enter by the ash-pit, and pass between the fire-bars, upwards through the hot coals above.

39. The Setting and Chimney of a Fixed Boiler.—In arranging the setting of any boiler, the three main points to be considered are—

(1) To allow of free expansion of the metal as it becomes heated.

(2) To see that no water, soot, or hot ashes can rest against the plates, for any one of these would rapidly corrode the steel and lead to a serious accident.

(3) To provide ample space for the passage of the heated gases, so that they may not be retarded, or wire-drawn, on their way to the chimney.

A cross-section of the setting of a Lancashire boiler, showing the circulation of the gases, was given in Fig. 67. Fig. 76 is a longitudinal section showing the sliding iron door or damper *D*, in the passage leading to the chimney, by closing which the stoker can regulate the draught.

The front of the boiler is free of the brickwork, so that it can move forward when expansion takes place.

Steel expands ·000,0066 foot, per foot, for each degree its temperature is raised. This boiler is 28 feet long, and for producing steam at 80 lbs. pressure per square inch, its temperature must be raised to 270° above the normal atmospheric temperature; its length will, therefore, be increased when hot by—

$$\begin{aligned} &\cdot 0000066 \times 28 \times 270, \text{ feet} \\ &= 0{\cdot}05 \text{ foot} \\ &= 0{\cdot}6 \text{ inch.} \end{aligned}$$

Consideration (2), mentioned above, is provided for by setting the boiler upon triangular fire-brick blocks, which stand 6 inches higher than the floor of the side flues (see Fig. 67). This allows for a considerable accumulation of soot, and keeps the plates clear of all moisture.

The bottom flue is 3 feet 6 inches broad, and 2 feet deep. The two side flues together are rather larger in area, as they reach up to the top of the water space in the boiler, and are 6 inches broad at the narrowest part, to allow for cleaning.

The chimney for this boiler is $3\frac{1}{2}$ square feet in section at the top.

Where one chimney serves several boilers, it is usual to

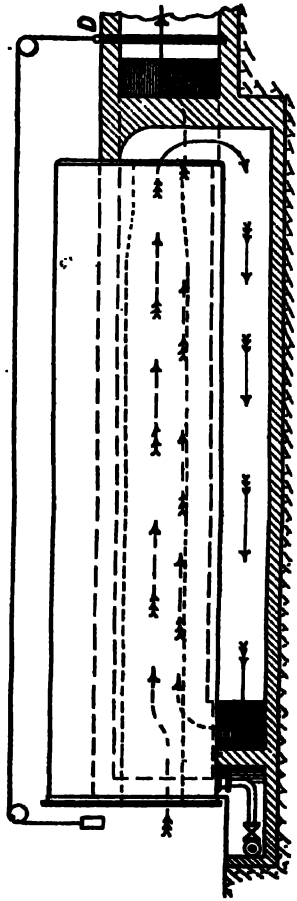


FIG. 76.—Longitudinal section of the setting of a Lancashire boiler. The arrows indicate the path followed by the furnace gases.

allow 1 square foot of cross-section for 10 square feet of grate area.

The use of a tall chimney is to produce a draught. Gases are expanded by heat, and therefore the products of combustion in the chimney (which, when cold, would be slightly denser than air, on account of the added weight of the burnt coal) are, owing to their higher temperature, somewhat lighter than the air. For this reason they rise through the chimney, as a loosely fitting cork would rise through a vertical pipe immersed in water. Cold air rushes in through the ash-pit and fire-bars to take their place, and this, in its turn, becomes heated, and rises.

A strong draught becomes of importance when it is desirable to reduce to a minimum the size of the furnace and boiler required to produce a given amount of steam. This is especially the case at sea, where the effect of the funnel is frequently supplemented by a fan, and in locomotives, where the exhaust steam is used to create a rush of air.

40. Calculation of the Stresses in a Boiler Shell.—The stress in the cylindrical portion of a boiler, due to an internal steam pressure, can be determined as follows—

Let d = diameter of boiler in inches (see Fig. 77).
l = the distance, in inches, between any two neighbouring cross-sections AFD and BEC (Fig. 77).
t = the thickness of the plates in inches.
f = the stress in the plates in lbs. per sq. in.
p = the steam pressure in lbs. per. sq. in.

Imagine the portion of the shell under consideration to be divided into two equal parts, by the plane $ABCD$.

It is obvious that the resultant force on either of these parts, normal to the plane $ABCD$, calls into play an equal and opposite tension across the sections AB and DC.

This tension will not be altered if one of the parts is replaced by a flat, rigid plate.

Therefore tension in shell = resultant pressure on remaining part
= pressure on flat plate
$= p \times d \times l.$

But tension in plate $= f \times 2t \times l.$

$$\therefore f \times 2t \times l = p \times d \times l.$$

$$\therefore f = \frac{pd}{2t}.$$

Let us apply this rule to find the stress in the shell plates of the boiler described above.

$$\text{Here } p = 80$$
$$d = 90$$
$$t = \tfrac{1}{2}$$
$$\therefore f = \frac{80 \times 90}{2 \times \frac{1}{2}}$$
$$= 7{,}200 \text{ lbs. per sq. in.}$$

At the joint about one-third of the metal is cut away for the rivet-holes, so the force there will have to distribute itself over the remaining two-thirds, which will increase the stress in the ratio of 3 to 2, making it

$$\frac{7200 \times 3}{2} = 10{,}800 \text{ lbs. per sq. in.}$$

(a figure almost identical with that given on page 48, as a safe stress for mild steel).

We found previously that the total pressure on each end plate of the boiler was 154 tons or 346,000 lbs. This force causes a longitudinal tension in the shell which is distributed over the whole cross-section. Therefore the longitudinal tension per square inch

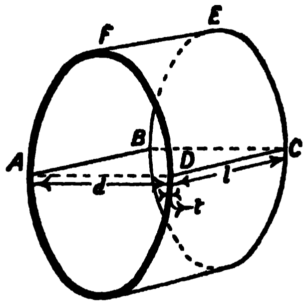


FIG. 77.

$$= \frac{346{,}000}{d \times \frac{22}{7} \times t}$$
$$= \frac{346{,}000 \times 7 \times 2}{90 \times 22}$$
$$= 2{,}450 \text{ lbs. per sq. in.}$$

which is only about one-third of the circumferential stress.

Unfortunately no simple rules can be found for determining the stresses in either the end plates or the flues.

EXAMPLES VII.

1. A small Cornish boiler has a furnace 5 feet long and 3 feet broad, how many pounds of water would you expect it to evaporate per hour?

2. Mention four qualifications of a good boiler.

3. What advantages has the Lancashire over the Cornish boiler?

4. The Cornish boiler in question 1 is 20 feet long and 6 feet in diameter. Its furnace tube is 3 feet in diameter. There are no cross tubes, and the external flues surround two-thirds of the shell and back plate. Calculate the ratio of heating surface to grate area.

5. Sketch two views of the riveting in the shell of a Lancashire boiler, indicating the direction of the seams.

6. What is meant by caulking a boiler?

7. Sketch a manhole door in position.

8. Sketch a gusset stay, explain its use, and show how it is attached.

9. Why must not the gusset stays in a boiler be placed too near the furnace tubes?

10. Sketch two views of a joint in the furnace tubes of a Lancashire boiler, and state why it is made in the form shown.

11. Sometimes the above joints are made by riveting angle rings round the ends of each section. Is this a better or a worse arrangement than that shown in Fig. 74?

12. Sketch one of the cross water-tubes in a Lancashire boiler, and state its uses.

13. Why is a fire-brick bridge built in a furnace tube?

14. Sketch the furnace of a Lancashire or Cornish boiler, indicating the arrangements for stoking and admitting air.

15. Air enters the ash-pit of a Lancashire boiler; state what occurs to it before it is discharged from the chimney.

16. Why is a Lancashire boiler set on raised blocks of fire-brick?

17. Draw a plan of a Cornish boiler with its setting, indicating the flues by dotted lines.

18. A cylindrical boiler 8 feet in diameter is to withstand a working pressure of 100 lbs. per square inch. Calculate to the nearest $\frac{1}{8}$ inch the thickness of the shell, allowing a stress of 10,000 lbs. per square inch, and neglecting the effect of the joint.

19. In a joint with a single row of rivets (see Fig. 71) the plates are $\frac{1}{2}$ inch thick, the rivets are $\frac{13}{16}$ inch diameter and $1\frac{7}{8}$ inches apart; calculate the efficiency of the joint (*i. e.* the ratio of the cross-section of metal left after drilling the rivet-holes to the original cross-section).

20. Make a longitudinal and also a transverse section of a Lancashire boiler with its brickwork settings. Indicate the course of the

gases through the internal and external flues of the boiler to the chimney. Show also the construction of the fire-bridge, and method of supporting the fire-bars. (S. and A. 1896.)

21. Sketch and describe the construction of the front end plate of either a two-flued Lancashire boiler or a marine boiler, and show how it is connected with the shell plates, and how it is otherwise strengthened or stayed. (S. and A. 1899.)

CHAPTER VIII.

BOILER MOUNTINGS.

41. Steam Pipes and Separators.—The pipes connecting a boiler and engine must have freedom to expand, when heated by the steam passing through them, or they will become strained and leak at the joints.

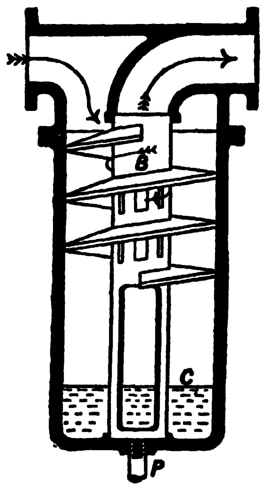


FIG. 78.—Wet steam separator.

A right angle bend, with long arms, which can yield a little laterally, is the simplest means of providing this freedom.

For safety a stop valve is inserted close to both engine and boiler.

The pipes are sometimes given a slight inclination towards the boiler, so as to keep them free from water, but, if this is done, a cock must be fitted to drain them while the stop valve is closed. Fatal explosions have occurred more than once, owing to the violent hammering action set up when steam is suddenly allowed to enter a long pipe filled with water.

It is safer and more satisfactory to insert, close to the engine, a **steam separator**, one form of which is shown in Fig. 78. Steam mixed with the moisture due to priming or condensation enters at *A*, and acquires a rotary motion as indicated by the arrows. The centrifugal forces thus set up cause the heavy particles of water to collect at the outside of the vortex formed, and the lighter, gaseous steam is drawn off in a dry condition through the central pipe *B*. The water, on the other hand, accumulates at *C*, whence it can be drained away through the pipe *P*. A gauge glass is usually fitted to show the amount of water present.

42. The Stop Valve.—Fig. 79 shows a stop valve suitable for pipes of from 3 to 12 inches diameter. The seating *S* for the valve is made of specially hard bronze. It is screwed into a split ring sprung into a recess turned in the diaphragm of the cast-iron casing. It is thus readily replaced when damaged or worn, and it is free to expand with heat. The latter consideration is of importance as the coefficient of expansion for bronze is greater than that for iron.

The valve *V* is made of bronze in the smaller sizes, but in the larger sizes it is made of cast iron with a bronze ring screwed to it to form the steam joint. It is guided by a projection passing through a light frame supported beneath it.

The bronze spindle *R* is inserted in a recess on the upper side of the valve and is retained in place by a screwed cap. It has a screw thread cut upon it which engages with the crosshead *C*, and by means of this thread the valve is raised or lowered by turning the hand-wheel *H*. The crosshead is placed outside the valve casing so that the wearing of the

screw may be under observation. The gland *G* prevents leakage of steam round the spindle.

The "lift" of the valve need never exceed one quarter of its diameter *d*, for at that elevation the steam passage around it

$$= 3{\cdot}14\, d \times \tfrac{1}{4} d$$
$$= 3{\cdot}14 \frac{d^2}{4}$$
$$= \text{the cross-section of the pipe.}$$

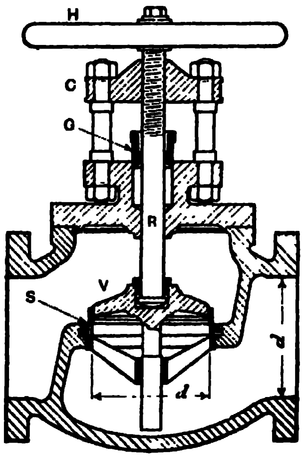


FIG. 79.—Bailey's Patent Steam Stop Valve.

Frequently the stop valve does not open directly into the boiler, but into a separator consisting of a hollow casting, in the form of an inverted T, with a number of holes on the upper sides of the horizontal arms. This prevents spray being carried away with the steam.

On locomotives a stop valve that can be quickly adjusted is essential for regulating the speed; a common form is shown in Fig. 80. A dome is fitted on the top of the boiler to increase the steam space (see Fig. 122), and the regulator is

placed within this. The rod *R* (Fig. 80) protrudes through the back of the boiler, and can be rotated by the driver. A small crank upon it actuates, through the link *L*, two flat valves which slide over a facing on the end of the steam-pipe. The inner valve has a slot, in place of a round hole, at its lower end; hence a small rotation of *R* raises the outer valve alone, and so opens the small port *S*. Through this the limited quantity of steam required to start the engine without

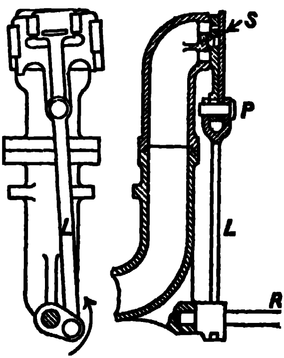


FIG. 80.—Locomotive regulator.

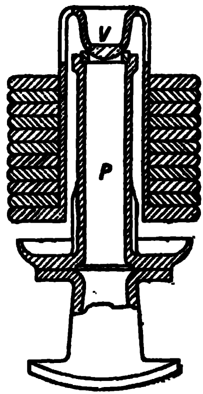


FIG. 81.—Dead weight safety valve.

shock can pass. A further rotation of *R* moves both valves and opens the large ports.

43. Safety Valves.—These are used to limit the maximum steam pressure possible in a boiler. Fig. 81 is an example of the simplest type.

The top of the branch pipe *P* is closed by the brass valve *V* which is loaded with a pile of cast-iron discs placed on a suitable carrier. If the upward pressure of steam on the valve is greater than the downward pressure of the weights upon it, it will lift and allow the steam to escape.

Ex. 1.—A safety valve two inches in diameter is to limit the steam pressure in a boiler to 80 lbs. per square inch; calculate the weight that must be placed upon it.

$$\text{Area of valve} = \frac{22}{7}\text{ sq. inches.}$$

$$\therefore \text{Total pressure on valve} = \frac{22 \times 80}{7} = 251 \text{ lbs.}$$

$$\therefore \text{Load required} = 251 \text{ lbs.}$$

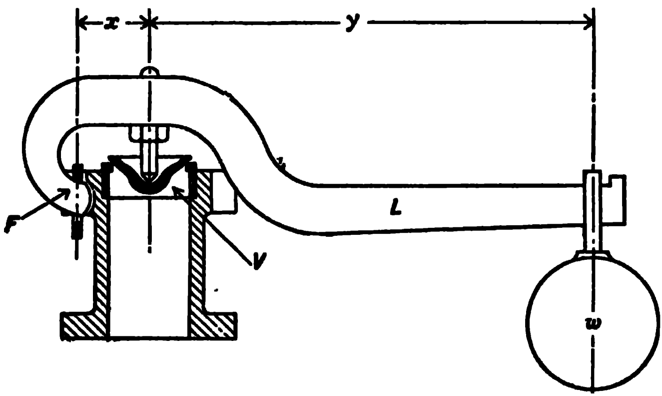


FIG. 82.—Lever safety valve.

It is usual to reduce the heavy weight required to load a large valve by interposing a lever, as shown in Fig. 82. The lever *L* turns about the steel fulcrum *F* and carries a weight *w* near its extremity; a pointed stud screwed into it bears upon the valve *V*.

Let *P* be the downward pressure on the valve; then by taking moments about *F* we have—

$$P \times x = w(x + y)$$
$$\text{or } P = w\frac{x + y}{x}$$

If the student has not previously studied levers he should

verify this statement experimentally. A bar of wood (Fig. 83) may be used as a lever, and any fixture, say the edge of a table, as fulcrum, while the upward pull of a spring balance may be used to represent the steam pressure tending to lift the valve.

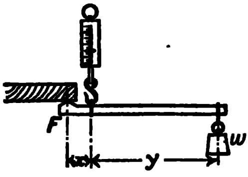


FIG. 83.

Ex. 2.—A 2-inch lever safety valve is to blow off at 80 lbs. pressure per square inch; the distances of the valve centre and the weight from the fulcrum are $2\frac{1}{2}$ inches and 15 inches respectively; find the load required.

From *Ex. 1*, the total pressure of the steam on the valve = 251 lbs.

$$\therefore P = 251 \text{ lbs.}$$
$$x + y = 15 \text{ inches.}$$
$$x = 2\tfrac{1}{2} \text{ inches.}$$
$$\text{Now } P = w\frac{x+y}{x}$$
$$\text{or } w = P\frac{x}{x+y}$$
$$= 251 \times \frac{2\frac{1}{2}}{15}$$
$$\therefore w = 42 \text{ lbs.}$$

NOTE.—This result would really be rather too large, as no allowance has been made for the weights of the lever and valve.

Gravity-loaded safety valves can only be used on stationary boilers, in all other cases the weights must be replaced by springs.

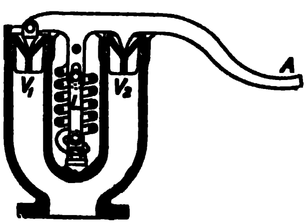


FIG. 84.—Ramsbottom's locomotive safety valve.

A lever safety valve, in which the weight w is replaced by an inverted spring-balance, was used for many years on locomotives, but unscrupulous drivers and firemen found that they could save themselves work by tightening the spring. To prevent this, the Ramsbottom valve (Fig. 84) was

introduced. In this the load, when once set, cannot be increased; on the other hand, the driver can relieve either of the valves V_1 and V_2, to make sure that they are quite free, by pressing the arm A upwards or downwards.

The loose links L prevent the valves being blown away if the spring breaks.

The reader will observe that the load on a valve is always applied at a point below the rim which supports it; this prevents it canting over when displaced.

It should be noted that, as a spring-loaded valve opens, the pressure upon it increases. In a gravity-loaded valve, on the other hand, the pressure remains constant. The latter has, therefore, some slight advantage over the former.

44. The Feed Pump.—The water supply has to be forced into a boiler against the pressure of the steam; Fig. 85 is a sketch of a simple pump for this purpose. The plunger P is driven by the main engine or by an auxiliary steam cylinder placed in the boiler-house. As it moves

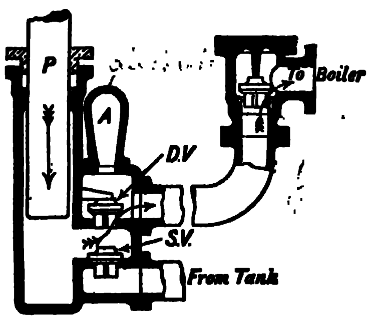


FIG. 85.—Feed-pump and check valve.

upwards water flows in through the suction valve SV to take its place. On the return stroke this water is driven out of the pump-barrel again, and, since its pressure closes the suction-valve, it can only escape by lifting the delivery valve DV and passing along the feed-pipe.

Fig. 85A represents a larger and more efficient feed-pump, in which the pressure of the steam, in the upper part, is transmitted directly to the water, in the lower part, through the rod 10.

This pump is double acting, the operations performed on each side of the plunger (20) being similar to those described above for a single-acting pump. The figure shows the suction and delivery valves (19 and 14) for the upper side of the plunge only, those for the lower side are behind these and are exactly similar. The valves consist of groups of small circular discs mounted on central pins.

The main slide valve for the steam cylinder is cylindrical and is moved horizontally by the pressure of steam upon its piston-shaped ends. This pressure is regulated by an auxiliary valve sliding upon a flat portion of the back of the main valve, and actuated by the piston-rod through the lever (5) and the rod (2).

When the piston (12) reaches the top of the cylinder, the auxiliary valve will be raised and will admit steam to the far end of the main valve so that the latter will be driven towards the observer. In that position it will connect the upper end of the cylinder with the steam chest and the lower end with the exhaust pipe. When the piston reaches the bottom of the cylinder the auxiliary valve will admit steam to the near end of the main valve and connect the far end with the exhaust; the main valve will thus be driven away from the observer so as to admit steam to the lower end of the cylinder and connect the upper end with the exhaust.

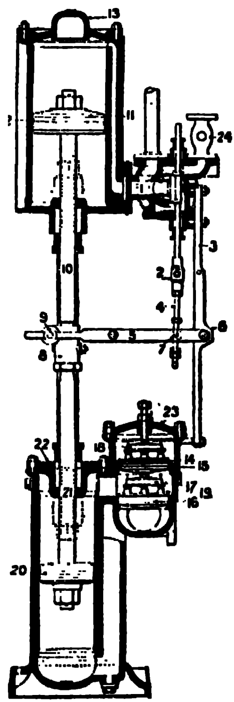


FIG. 85A.—Weir Feed Pump.

There is always a second delivery valve, or *check valve*, called also a "non-return" valve, close to the boiler, to allow of the pump being disconnected while steam is up. This may consist, as in Fig. 85, of a simple "mushroom" valve, with a fixed stop above it to keep it from rising too far.

If the feed tank is at a higher level than the boiler, there is a danger of the latter being flooded with water when steam is not up. To prevent this the stop, mentioned above, is replaced by a screwed spindle, similar to that in Fig. 79, but with a plain end, by means of which the valve may be held down firmly upon its seat.

A pipe is fitted inside the boiler leading the feed water from the check valve to some point where its delivery will best promote circulation. In a Lancashire boiler, for example, it is discharged horizontally at about the level of the furnace crowns, 9 or 10 feet from the front.

In locomotives steam is used directly to force water into the boiler through an *injector*, the action of which unfortunately involves considerations which cannot be entered into here for lack of space.

Ex. 3.—A feed-pump plunger 2 inches in diameter is driven by an eccentric of $1\frac{1}{2}$ inches throw, keyed to a shaft making 140 revolutions per minute. Find the cubic feet of water forced into the boiler per minute, and the horse-power absorbed, if the steam pressure is 80 lbs. per square inch.

$$\text{Area of plunger} = \tfrac{22}{7} \text{ sq. inches.}$$
$$\text{Stroke of plunger} = 3 \text{ inches.}$$
$$\therefore \text{ Water discharged into boiler per in-stroke} = \frac{3 \times 22}{7 \times 1728} \text{ cubic feet.}$$
$$\therefore \text{ Water discharged into boiler per minute} = \frac{3 \times 22 \times 140}{7 \times 1728}$$
$$= 0{\cdot}76 \text{ cubic foot.}$$
$$\text{Pressure on plunger during in-stroke} = 80 \times \tfrac{22}{7} \text{ lbs.}$$
$$\text{Distance moved against this pressure per minute} = \frac{140 \times 3}{12} \text{ feet.}$$
$$\therefore \text{ Horse-power absorbed} = \frac{80 \times 22 \times 140 \times 33}{7 \times 12 \times 33{,}000}$$
$$= 0{\cdot}27 \text{ horse-power.}$$

45. The Blow-off Cock.—This is connected to the lowest part of the boiler, and is used for drawing off the water. The pit and connections for the blow-off cock are shown in Figs. 69 and 76, and the cock itself in Fig. 86.

It is made of gun metal and packed with asbestos. A box-key is used for turning it, and a projection on this,

passing through a corresponding slot in the gland cover, prevents its removal before the cock is properly closed; this is a very necessary precaution, as leakage in such a place might easily escape observation.

46. Water-level Gauges.—Two glass water-level gauges,

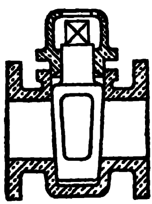


FIG. 86.—Blow-off cock.

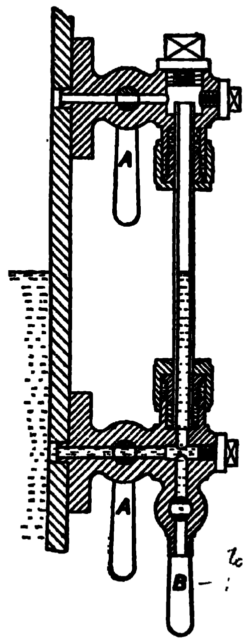


FIG. 87.—Water-level gauge glass.

similar to Fig. 87, are usually fitted, as the glasses are liable to break, and take some time to replace. One end of each is connected with the boiler above the highest allowable water-level, and the other below the lowest. They can be disconnected by means of the cocks *A*, *A*, and their accuracy may be checked from time to time by closing these and

opening the "blow-through" cock *B*. If, on closing *B* and re-opening *A*, *A*, the water does not immediately return to its previous level in the glass, it is evident that one of the passages has become choked.

For additional safety when high pressures are used a metal ball is placed in a cavity in each of the gauge-glass mountings. These form automatic valves which normally rest open by their own weight, but the sudden rush of water and steam which occurs when a glass breaks is sufficient to lift and close them.

47. The Pressure Gauge.—This consists of an oval tube *T*, Fig. 88, bent into an arc of a circle, one end of which is connected with the boiler; the other end is closed, and is linked to a rack, gearing with the pinion wheel *P*, which carries a pointer. The application of internal pressure to such a tube is found to cause its free end to move outwards through a distance proportional to that pressure; this motion is registered by the pointer.

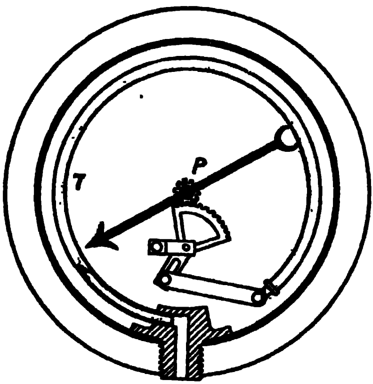


Fig. 88.—Steam pressure gauge.

Heat would also cause the tube to change its form, and therefore steam must not be allowed to act directly upon it, but only through the column of water which will collect automatically, by condensation, if the connecting pipe is made in the form of a syphon, and is of sufficient length.

48. Other Mountings.—A small **Vacuum Valve** opening inwards should be fitted to a boiler to admit air when the fires are drawn and the steam condenses.

A Scum Cock (similar to the blow-off cock, but connected to an internal pipe or trough near the surface of the water) allows of scum being discharged without interfering with the working of the boiler.

A Low-water Indicator is fitted to large boilers. It is actuated by a float placed upon the water which, if it falls too low, releases a safety valve, blows a whistle, or gives in some other way the necessary warning.

A Fusible Plug, consisting of a brass tube filled with a mixture of lead and tin, is screwed into the furnace tube above the grate. The soft metal will melt if the temperature of the boiler becomes dangerously high, and the escaping steam will put out the fire.

EXAMPLES VIII.

1. How is expansion allowed for in setting up steam-pipes?

2. How would you take the steam stop valve (Fig. 79) to pieces for repairs?

3. What is the greatest lift that need be allowed for a 6-inch stop valve? Give a reason for your answer.

4. What parts of a stop valve are made of brass, and why is this metal chosen for them?

5. Why is a special form of regulator necessary on locomotives?

6. What load must be placed on a 2½-inch dead weight safety valve, if it is to "blow off" at 60 lbs. pressure per square inch?

7. A 4-inch dead weight safety valve carries a load of 550 lbs. At what steam pressure will it lift?

8. In the model shown in Fig. 83, $x = 4$ inches, $y = 10$ inches, and $w = 4$ lbs. What load will the balance register?

9. In a 2-inch lever safety valve the fulcrum is 3 inches from the centre of the valve, and the weight is 15 inches from the fulcrum. What load must be used for the valve to blow off at 100 lbs. pressure per square inch?

10. How could a gravity-loaded lever safety valve be modified for use at sea?

11. A boiler generates 3,000 lbs. of steam per hour; its feed-pump plunger is 2 inches in diameter and has a stroke of 12 inches. How many strokes (in and out) must it make per minute?

1 lb. of water = ·016 cubic foot.

12. In the pump shown in Fig. 85, what would happen if the pressure in the boiler fell below that of the atmosphere?

13. Sketch a glass water-level gauge, and state the use of the three cocks fitted to it.

14. How would you test a gauge glass to see that it was registering the correct water level?

15. Why is a vacuum valve fitted to a boiler?

16. What is the use of a fusible plug? Where should it be placed?

17. Make a rough sketch of any boiler, and indicate the position of the following mountings upon it:—safety valve, stop valve, check valve, blow-off cock, and gauge glass.

18. Describe with sketches any form of locomotive regulator valve to admit steam from the boiler to the cylinder steam-chests. (S. and A. 1900.)

19. Sketch the construction of a lever safety valve with balance weight, and state under what circumstances such a construction could not be used. If the lever be 16 inches in length, and the centre of the valve seat is 4 inches from the fulcrum, while the diameter of the valve is 4 inches; find the weight to be placed at the end of the lever so that steam may blow off at a pressure of 45 lbs. per square inch, the weight of the valve and of the lever being neglected. (S. and A. 1896.)

20. Explain and show, with sketches, the construction and action of the force pump employed for feeding the water into a boiler when an injector is not used.

Sketch also in section the clack or non-return valve attached to the boiler. How is the pump prevented from forcing water into the boiler when the engine is running but a supply of water is not required?

The ram of such a pump is 2 inches in diameter, and has a stroke of 24 inches. How many gallons of water (neglecting leakages) would be forced into the boiler for each 1,000 double strokes (one forward and one backward) of the pump?

1 gallon = ·16 cubic foot. (S. and A. 1897.)

21. Describe and show by a sketch the construction of Ramsbottom's safety valve for a locomotive engine. How are the lever and valves prevented from flying off in the event of the spring breaking? If in a Ramsbottom valve the two valves each have a diameter of $2\frac{1}{2}$ inches, what would be the pull on the spring when steam is just blowing off at a gauge pressure of 140 lbs. to the square inch? (Neglect the weight of the valves and connections.) (S. and A. 1897.)

CHAPTER IX.

HEAT.

49. Combustion.—The thoughtful student will by this time have realized that the power of a steam-engine is supplied from the fuel burnt under its boiler; this is its food, so to speak, the mechanism corresponds merely to the digestive organs, the arteries, the nerves, and the muscles. Our reason for using the steam-engine at all, is that its fuel costs very much less, in proportion, than the food of horses or other beasts of burden. The following figures are instructive—

One hundred horses working 8 hours a day would eat per day 2,800 lbs. of food (corn and hay), costing, say, £9.

To drive a 100 horse-power engine for 8 hours 2,400 lbs. of coal must be consumed, costing, say, 18 shillings.

Though oil, wood, and even straw are burnt, under special circumstances, in boiler furnaces, coal is by far the commonest fuel, because it produces heat at the least expense.

When fuel is placed so that a stream of air can pass through it, and ignited, a chemical action takes place which produces a large amount of heat.

Air consists of two gases, *oxygen* and *nitrogen*, mixed in the proportion of 1 lb. of the former to $3\frac{1}{3}$ lbs. of the latter.

Fuels, on the other hand, consist principally of carbon and hydrogen. During combustion the oxygen of the air combines with both of these, forming carbon dioxide gas with the carbon, and steam with the hydrogen.

If carbon is burnt in an insufficient supply of oxygen carbon monoxide gas will be formed. In this reaction only $\frac{3}{10}$ of the heat available is developed. Carbon monoxide will itself burn in oxygen and form carbon dioxide when the remaining $\frac{7}{10}$ of the heat will appear.

When coal is first heated gaseous combinations of hydrogen and carbon are given off which also require oxygen for their combustion.

In a well-designed and properly stoked boiler, just sufficient oxygen will be supplied above the fire-bars to burn all the inflammable gases formed (the carbon monoxide and hydrocarbons), and the back of the fire at least will be kept bright enough to ensure their ignition.

The least amount of air which must be supplied to any furnace may be estimated as follows:—

A pound of coal contains ·8 to ·9 lb. of carbon, ·05 lb. of hydrogen and a small quantity of oxygen, sulphur and ash. Of the products of combustion the carbon dioxide contains $2\frac{2}{3}$ lbs. of oxygen for every pound of carbon, and the water contains 8 lbs. of oxygen for every pound of hydrogen. We may say, therefore, that each pound of coal requires

$$·9 \times 2\tfrac{2}{3} + ·05 \times 8, \text{ or } 2·8 \text{ lbs. of oxygen,}$$

and this will be contained in

$$2·8 (1 + 3\tfrac{1}{3}), \text{ or } 12·13 \text{ lbs. of air;}$$

12 lbs. may be remembered as a round number. This quantity is always greatly exceeded in practice, since it is impossible to mix the oxygen and coal so thoroughly that none of the former gets through unconsumed. 18 to 20 lbs. of air per pound of coal is the least practicable allowance.

50. Temperature.—The term heat has been used up to this point to express the cause of certain phenomena with which all are acquainted; we must now go a step further, and distinguish between the *quantity* of heat in a body and its *intensity*.

Every reader could tell the difference between hot water and cold, because he can estimate roughly, through his sense of touch, the intensity of the heat in each, or their *temperature;* he might also have distinguished between them by observing that, weight for weight, the hot water occupied the greater volume. This expansion of substances with heat, which is almost universal, can be accurately determined, and it provides us with a ready means of measuring temperatures. Mercury is used as the expanding substance, as it is more suitable for the purpose than water. In a mercurial thermometer a glass bulb *B*, Fig. 89, at the end of a fine tube is filled with this liquid; the tube is then sealed, all trace of air being first removed from it. When the bulb is

heated, the mercury expands more than the glass, so that some of it has to pass into the tube, and this quantity measures the difference of expansion, and therefore the change of temperature.

To establish a standard of comparison between the readings on all such thermometers it is necessary to fix upon two definite temperatures at which the level of the mercury in their tubes may be compared. For this purpose the freezing temperature and boiling temperature of pure water are chosen, as these are quite constant under the normal atmospheric pressure.

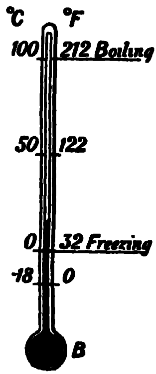


FIG. 89.—Thermometer with centigrade and Fahrenheit scales.

Unfortunately there are two systems in vogue for dividing the interval between the points thus found.

In the *Centigrade* system (left hand side, Fig. 89), used in many countries abroad, and by scientific men at home, the freezing-point is marked 0, and the interval is divided into 100 divisions, called **degrees centigrade**; thus the boiling-point is marked 100° C.

In the Fahrenheit system (commonly used in England), the freezing-point is marked 32, and the interval is divided into 180 parts called **degrees Fahrenheit**; thus the boiling-point is marked 212° F.

According to these divisions each degree Fahrenheit is $\frac{100}{180}$ or $\frac{5}{9}$ of a degree centigrade.

Ex. 1.—A Fahrenheit thermometer reads 68° F.; what would a centigrade thermometer read at the same temperature?

$$68^\circ \text{ F. means } 68 - 32 = 36^\circ \text{ F. above the freezing-point.}$$

$$36^\circ \text{ F.} = 36 \times \tfrac{5}{9} = 20^\circ \text{ C.}$$

∴ the mercury in the centigrade thermometer would stand at 20° C. above the freezing-point, and, as the latter is at 0° C., the reading on the scale would be 20° C.

51. Quantitative Measurement of Heat.—From measuring the intensity of heat in a body, the next step is to determine the quantity of heat required to make some definite change in that intensity. Before learning how this is done, the student should make two simple experiments which will illustrate some of the difficulties of the problem, and will show him the reason for our making quantitative measurements in the way we do.

EXPERIMENT 1.—Take two similar, thin, metal or glass vessels; into the first pour 1 lb. of water, and into the second pour 2 lbs.; heat each in turn for 5 minutes over the same gas-burner, or spirit lamp, keeping the water stirred, and noting the rise in its temperature.

It is reasonable to suppose that each vessel receives the same amount of heat, and yet the temperature in the first vessel will have risen twice as much as that in the second. This shows that the quantity of heat required to effect a given change of temperature depends upon the amount of material that has to be heated.

EXPERIMENT 2.—Put 1 lb. of iron nails, or iron filings, into a small vessel, standing in a larger vessel containing water. Heat the latter over a flame till its contents are raised to a temperature of 212° F.

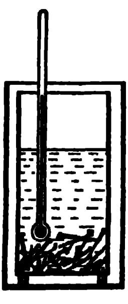


FIG. 90.

Pour a pound of water into a canister, and insert this in a slightly larger canister, letting it rest on slips of cork so that there may be a narrow air space all round it to prevent loss of heat by conduction or radiation (see Fig. 90). Note the temperature of the water. Let this be 62° F., for example.

Now plunge the nails into this water, stir it well, and note the reading of the thermometer. In the case taken, this would be about 77° F.

Neglecting small losses, the heat given up by the iron must equal that gained by the water, but the 1 lb. of iron has been cooled $212 - 77$, or 135° F., while the

same weight of water has been raised in temperature 77 – 62, or 15° F.

This shows us that the quantity of heat required to effect a given change of temperature in a given weight of a substance, depends upon the nature of that substance.

These two experiments taken together show that, to estimate heat quantitatively, three things must be known.

1. The nature of the material absorbing the heat.
2. Its weight.
3. Its change of temperature.

In this country the unit of heat adopted, called the British Thermal Unit, is as follows—

The British Thermal Unit is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

To be quite accurate the water should be defined to be at about 60° F., for the amount of heat required to raise a given quantity 1° F. varies slightly with the temperature.

The amount of heat in thermal units required to raise one pound of other materials through 1° F., has been carefully measured by experiments similar to Experiment 2. This quantity is called the **specific heat** of the material.

The following table of specific heats will be useful for future reference—

Material.	Specific heat.
Water	1·00
Iron	·11
Copper	·09
Fire-brick	·20
Flue gases at constant pressure .	·25

Ex. 2.—In a boiler furnace 20 lbs. of air are used per lb. of coal; if

the air enters the ash-pit at 80° F., and leaves the flues at 400° F., how much heat is carried up the chimney?

Weight of flue gases = weight of air + weight of coal
= 21 lbs.
Rise in temperature of gases = 400 − 80 = 320° F.
Specific heat of gases = ·25.
∴ heat carried away = 21 × 320 × ·25
= 1680 Th. U.

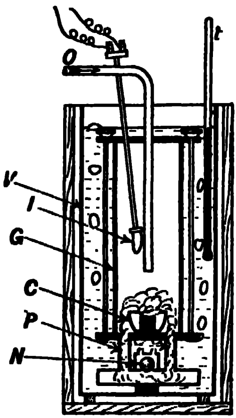


FIG. 91.—Coal calorimeter.

52. Heating Value of Fuels.—It is not easy to determine accurately the quantity of heat produced by the combustion of a given weight of coal; the student should, however, make some rough experiments for himself with a calorimeter similar to that shown in Fig. 91.

A sample of the fuel to be tested is ground to a fine powder, and compressed into a briquette. When the latter has been carefully weighed, it is placed in the porcelain crucible *C*, and is enclosed in a watertight casing, consisting of a glass cylinder *G*, held between two metal plates; rubber rings are inserted between the cylinder and plates to prevent leakage. This casing is immersed in water contained in an

outer vessel V which, in its turn, is surrounded by a wood covering, to protect it from loss of heat. A window in the side of the vessel V allows the progress of the experiment to be watched.

Pure oxygen gas is used in place of air, in order to ensure rapid and complete combustion. The gas may be supplied from a storage cylinder, and is introduced through the tube O.

The briquette is ignited by means of the platinum wire loop l, which can be brought into contact with it and then raised to a red heat by means of an electric current. The stream of fresh oxygen entering through O drives the products of combustion before it down the two short pipes P, and past the non-return valve N; so that they bubble up through the surrounding water, giving up their heat to it and keeping it stirred.

The rise in temperature of the calorimeter is noted by the delicate thermometer t.

Let w = weight of coal burnt.
W = weight of water in calorimeter.
T = rise in temperature of water.
K = the thermal units absorbed by the calorimeter, per degree rise of temperature (this is the sum of the weights of the immersed portions multiplied by their respective specific heats).

Then, the heating value of the coal per pound

$$= \frac{(W + K)\,T}{w} \text{ Th. U.}$$

For rough experiments the heat due to the electric current can be assumed to balance that lost by radiation.

The heating values of coal-gas and oil are more easily determined than that of coal, because they can be burnt continuously at a uniform rate.

A simple gas calorimeter, which may also be used for oil, is shown in Fig. 92. It consists of a hollow metal vessel, through which water can circulate, and which is protected

from loss of heat through radiation by a polished outer casing.

The gas, after passing through a meter (not shown), is burnt in the bunsen burner *B*. The products of combustion pass, first upwards, as indicated by the arrows, then downwards through a number of small tubes, where they give up their heat, and they finally escape into the air at about atmospheric temperature. The circulating water, which

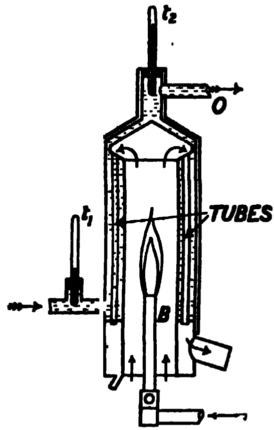


FIG. 92.—Calorimeter for gas or oil.

absorbs all the heat produced, enters at *I* and leaves at *O*. Its initial and final temperatures are indicated by the thermometers t_1, and t_2; and its rate of flow is determined by measuring the amount discharged in a given time.

Let G = cubic feet of gas burnt per min.
W = weight of water discharged per min.
T = rise of temperature of water in passing through calorimeter.

Then heating value of gas per cubic foot

$$= \frac{W T}{G} \text{ Th. U.}$$

The following figures should be committed to memory, as they are of frequent use to the engineer in making rough preliminary calculations.

(*a*) *One pound of coal is capable of producing from* 14,000 *to* 15,000 *British thermal units of heat, according to its quality;* 14,500 *is a convenient average value to remember.*

(*b*) *One pound of paraffin oil will produce about* 19,000 *thermal units.*

(*c*) *One cubic foot of lighting-gas will produce about* 650 *thermal units.*

The heat equivalent of methylated spirit, viz. 10,500 thermal units per pound, may be added to this list, as some students will doubtless be using it in making experiments on their own account.

53. Effect of Heat on Water.—It has been noticed already that at a certain temperature, called 212° F., and 100° C., water in an open vessel, under the normal atmospheric pressure, will boil; that is to say, a gas, named steam, is formed in it, which rises to the surface in bubbles and mixes with the air. If the boiling is continued long enough, all the water will turn to steam, and if the steam is collected and cooled it will change to water again.

To make the process clearer, let us suppose that the water is contained in a cylindrical vessel, and that the steam formed is prevented from escaping by a light piston. For clearness, we will suppose that the pressure of the atmosphere is removed and replaced by an equal weight resting on the piston. The reason for keeping this pressure carefully in mind will be seen later.

A (Fig. 92*a*) shows the water before it is heated; in *B* it is supposed to be boiling. Since the steam occupies a greater volume than the water from which it is formed, it has to raise the weight on the piston; hence it is easy to see that the water cannot boil unless the steam produced is at a sufficient pressure to overcome this weight.

Steam in presence of water is called *saturated steam* because, if it is cooled, some of it will immediately turn to water again.

Suppose that all the water has been turned into steam (as in *C*) and that heat is still applied to the vessel. The steam will continue to absorb this heat and will, as a consequence, expand. It is then called *superheated steam*, because it will part with the extra heat supplied to it before any of it changes back into water.

The steam generated in all boilers is of necessity saturated steam, and it is usually supplied to the engine in this condition; sometimes, however, it is superheated after leaving

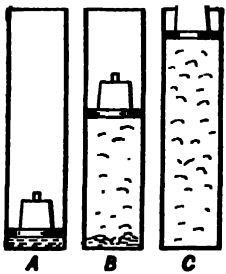


FIG. 92A.

the boiler. The advantages of the latter process will be dealt with in Chapter XII.

EXPERIMENT 3.—Take a thin vessel, pour into it one pound of water, and place it over a small steady gas or spirit flame. Keep the water well stirred and note its temperature every minute, till it has been boiling some minutes; then remove the flame, and re-weigh the water as quickly as possible.

Observations made by the author during an experiment of this nature are given below. The student should be able to make the same deductions from his own results, as are made from these.

Weight of vessel, 5 oz.
Weight of water and vessel before experiment, 1 lb. 5 oz.
Weight of water and vessel after experiment, 1 lb. $1\frac{1}{2}$ oz.
∴ Weight of steam produced

$$= 1 \text{ lb. } 5 \text{ oz.} - 1 \text{ lb. } 1\tfrac{1}{2} \text{ oz.}$$
$$= 3\tfrac{1}{2} \text{ oz.}$$

Time.	Temperature.	
7.23	40	
7.24	61	
7.25	82	
7.26	102	
7.27	120	
7.28	139	
7.29	158	
7.30	177	
7.31	194	
7.32	208	
7.32½	212	boiling commenced.
7.35	212	
7.38	212	
7.41½	212	flame removed.

In Fig. 93, *OAC* is a curve plotted between these times and the corresponding temperatures.[1] It will be seen from this that the thermometer rises steadily at first, then more slowly as steam begins to form, till it becomes stationary at 212° F.

It is safe to assume that the water was receiving heat at practically the same rate throughout the experiment. What then became of the heat after the boiling-point was reached? It must have been used up in generating the steam, and it must also have changed its nature in the process.

The term *Latent Heat* is applied to heat which is employed in the formation of steam, and which ceases to affect the thermometer.

Produce the straight part of the curve *OA* (Fig. 93) to

[1] The student will of course plot his own results on squared paper.

intersect a perpendicular *BCD* drawn through *C*. Then, if all the heat supplied had remained sensible heat, the final temperature of the water would be represented by *DB*, that is to say it would have been 394°. Since one pound of water was taken, 394 − 40 thermal units would, therefore, have been supplied.

It is evident from the figure that 394 − 212 or 182 of these units have changed to latent heat in generating $3\frac{1}{2}$ oz.

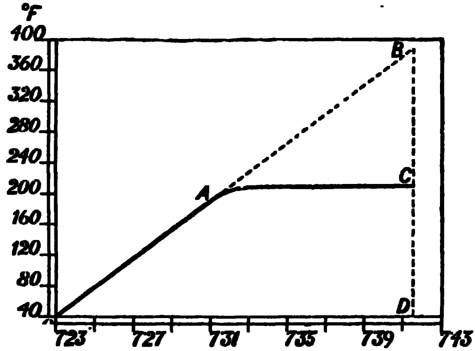


Fig. 93.

of steam. Therefore, according to the experiment, the latent heat of 1 lb. weight of steam is

$$\frac{182 \times 16}{3\frac{1}{2}} = 832 \text{ Th. U.}$$

Careful experiments made with delicate apparatus show that this figure is much too small, owing, probably, to some particles of unevaporated water being carried away by the steam. The correct quantity is **966 thermal units.**

When steam condenses, its latent heat changes back again into sensible heat, and therefore the results of Experiment 3 may be checked as follows—

Experiment 4.—Take a canister protected from loss of heat (like that used in Experiment 2), and pour into it

W lbs. of water at a temperature t. Blow steam into this through a short pipe, till the temperature has risen to say t_2.

The weight of water in the canister will thus be increased by w lbs., the weight of the steam condensed.

Let L equal the latent heat of one pound of steam.

The heat lost by the steam is

$$wL + w(212 - t_2)$$

The heat gained by the water is

$$W(t_2 - t_1)$$

These quantities are equal, as there is no loss or gain of heat; hence

$$wL + w(212 - t_2) = W(t_2 - t_1)$$
$$\therefore\ wL = W(t_2 - t_1) - w(212 - t_2)$$
$$\therefore\ L = \frac{W}{w}(t_2 - t_1) - (212 - t_2)$$

an equation from which L can be calculated.

The student must not imagine that the phenomenon of latent heat is confined to steam alone, it occurs when any liquid substance evaporates and also when any solid melts.

54. The total heat of Steam at any Pressure.—So far we have exclusively dealt with steam at atmospheric pressure, and we have found its temperature to be 212° F. If the pressure is raised, the temperature rises also, and if the pressure is lowered, the temperature falls.

EXPERIMENT 5.—Every student should verify these statements for himself by getting up steam in a small boiler, like that sketched in Fig. 94, consisting of a spherical vessel containing water and mercury. The temperature of the steam generated in this is measured by the thermometer T, and its pressure by the height of the column of merçury it will support in the vertical glass tube G. C is a cock for relieving the steam pressure.

Let M be the height of the column which can be supported by steam at a temperature t, and let A be the cross section of the tube G. The pressure of the steam can be calculated as follows—

The weight of a cubic inch of mercury = ·49 lb.

∴ The steam pressure on an area of A square inches supports ·49 × M × A lb. of mercury.

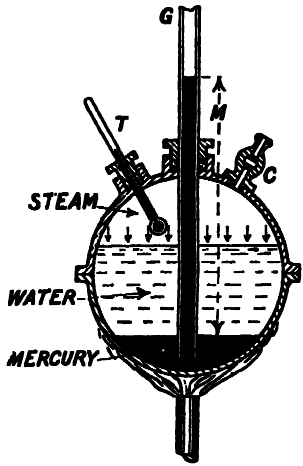


FIG. 94.—Marcet's experimental boiler.

∴ The steam pressure in lbs. per square inch

$$= \cdot 49 \frac{MA}{A}$$

$$= \cdot 49 \, M \text{ lb. per square inch}$$

A reading of the barometer should be taken before commencing the experiment, and the atmospheric pressure deduced from it.

A series of simultaneous readings of pressure and temperature may then be recorded as shown below

Barometric height = 30 inches.

∴ Atmospheric pressure = ·49 × 30

= 14·7 lbs. per sq. inch.

Height of Mercury Column in Inches = *M*.	Corresponding Pressure lbs. per sq. inch	Absolute Pressure lbs. per sq. inch.	Temperature of Steam $t°$ F.
0	0	14·7	212
5·7	2·8	17·5	221
12·4	5·1	20·8	230
20·0	9·8	24·5	239
28·8	14·1	28·8	248

The following method of performing Experiment 5 is given for the benefit of those readers who have to construct their own apparatus—

Heat a long glass tube about two inches from one end till it is red hot, then draw the short piece away. This will leave a closed end. Heat the glass again, in a "fishtail" burner, till it can be bent into the form of the letter "*J*," the long arm being open (see Fig. 95).

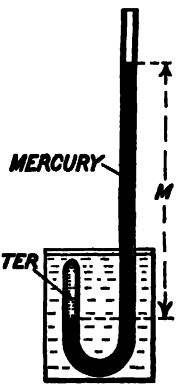


FIG. 95.

When the tube is quite cold, partially fill it with water. Boil this till only a small amount remains, and immediately plunge the open end into some mercury; the latter will then take the place of the steam as it condenses. The apparatus is now ready for the experiment.

Immerse the lower part of the "*J*" in a bath of oil or melted fat placed over a flame. Keep the bath well stirred, and note its temperature when the water begins to generate steam of sufficient pressure to lift the mercury. The pressure of this steam can be calculated from the difference of level, *M* (Fig. 95), of the mercury in the two arms of the tube. Its temperature is obviously that of the surrounding liquid.

M can be varied by adding or removing mercury, and it may even be made negative, in which case the water would be subjected to a pressure less than that of the atmosphere.

The student will see from the results he obtains that the temperature of saturated steam, or, what is the same thing, the boiling-point of water rises as the pressure increases, and also that there is a definite temperature for every pressure.

On the strength of this fact engineers might fit thermometers to their boilers in place of pressure-gauges, and state that the safety-valve blows off at such and such a temperature.

Fusible plugs (see § 48) are in fact frequently used as temperature safety-valves.

The *latent*, as well as the *sensible* heat, of saturated steam changes with the pressure; it decreases, however, instead of increasing, as the latter rises.

There is, unfortunately, no simple method of demonstrating this fact. Regnault, a French scientist, was the first to establish it. He made, about 1847, a most careful and laborious series of experiments, and from these he proved that the following simple formula expressed very nearly the total heat H (*i.e.* the sensible heat plus the latent heat) required to convert a pound of water at 32° F into saturated steam at any temperature $t°$ F.

$$H = 1082 + \cdot 305\, t.$$

If the centigrade scale of temperatures is used, and the unit of heat is defined as the quantity required to raise one pound of water one degree centigrade, this equation becomes

$$H = 606\cdot 5 + \cdot 305\, t.$$

A table worked out from Regnault's results is given at the end of the book (page 219). The student should, as an exercise, plot curves on squared paper between the absolute pressure of steam and its volume, temperature and total heat. If these are drawn to a large scale they will be useful for reference.

When water at some higher initial temperature t_f, say, has to be dealt with, the heat required to convert it into steam at a temperature t is, of course,

$$1082 - (t_f - 32) + \cdot 305\, t \text{ Th. U.}$$

$$i.e.\ 1114 - t_f + \cdot 305\, t \text{ Th. U.}$$

The latter formula should be committed to memory.

We are now in a position to calculate the heat received by the steam generated in a boiler, and to find what proportion this bears to the heat produced in its furnace, a most important consideration to every steam user, for waste of heat means waste of fuel, and therefore waste of money.

The best way of showing the efficiency, or otherwise, of a boiler is to draw up a balance-sheet showing how the heat from each pound of coal burnt is accounted for. The method will be made plain by an example.

Ex. 3.—In a certain boiler trial the following figures were noted. Draw up from them a heat balance-sheet.

Lbs. of coal burnt	2,000
Heat equivalent of coal Th. U.	14,500
Lbs. of air supplied per lb. of coal	24
Temperature of boiler-house °F.	80
,, at base of chimney °F.	430
Lbs. of water evaporated	18,000
Temperature of feed-water °F.	100
,, ,, steam °F.	370

Heat lost in flues per lb. of coal (see page 127)

$$= 25 \times (430 - 80) \times \cdot 25$$
$$= 2187 \text{ Th. U.}$$

Heat given to each lb. of water

$$= 1114 - 100 + \cdot 305 \times 370$$
$$= 1126 \cdot 8.$$

Lbs. of water evaporated per lb. of coal

$$= \frac{18000}{2000} = 9 \text{ lbs.}$$

∴ Heat given to water per lb. of coal

$$= 9 \times 1126 \cdot 8$$
$$= 10{,}141 \text{ Th. U.}$$

BALANCE-SHEET.

	Th. U.		Th. U.
Heat given out in burning 1 lb. of coal	14,500	Heat given to 9 lbs. of steam	10,141
		Heat lost in chimney . .	2,187
		Balance being heat lost by radiation, etc.	2,172
	14,500		14,500

EXAMPLES IX.

1. State briefly what happens when coal burns.

2. Show how the least quantity of air required to burn one pound of coal is estimated. Why is this quantity always exceeded in practice?

3. Sketch and describe a thermometer. For what purpose is this instrument used?

4. How is a thermometer graduated?

5. The normal temperature of the human body is 98° F. Express this in degrees centigrade.

6. On a certain day the mean temperatures at Paris and London were 18° C. and 65° F. respectively. Compare these figures.

7. Distinguish between the intensity of the heat in a body and the quantity of heat in that body. Define the units in which each is measured.

8. A swimming bath contains 500 tons of water; how many thermal units are required to raise its temperature 14° F.?

9. Define specific heat.

10. Draw a diagram on squared paper, showing the loss of heat in a chimney when the air supply varies from 12 to 30 lbs. per lb. of coal.
Temperature of boiler-house 80° F.
" " chimney 480° F.

11. Describe an experiment for determining the calorific value of coal-gas.

12. Calculate the calorific value of a sample of coal from the following experimental results—

Weight of sample	= ·004 lb.
Weight of water in calorimeter	= 6·3 lbs.
Constant of calorimeter (*i.e.* heat absorbed per degree rise of temperature)	= ·7 Th. U.
Initial temperature of water	= 55·3° F.
Final temperature of water	= 63·7° F.

13. Calculate the weight of coal required to heat the water in question 8, assuming the efficiency of the furnace to be $\frac{1}{2}$.

14. If coal costs 20 shillings per ton and oil 26 shillings per ton, which should be used for producing steam?

15. Define the terms saturated and superheated steam.

16. 1 lb. of saturated steam is condensed in a vessel containing 27 lbs. of water at 60° F.; what will be the temperature of the mixture?

17. An engine discharges 2,000 lbs. of exhaust steam per hour; if this is used to raise the temperature of an equal weight of feed-water from 60° F. to 200° F., what saving in coal should be effected?

18. In a boiler trial it was found that 8 lbs. of feed-water, at a temperature of 50° F., were converted into steam, at 130 lbs. pressure, per lb. of coal burnt; what percentage of the heat generated by the latter was usefully employed?

NOTE.—The total heat of the steam will be found in the Appendix.

19. In another boiler of the same efficiency the working pressure is 20 lbs. per square inch, and the feed-temperature 200° F.; how many pounds of water will be evaporated in it, per pound of coal?

20. Describe an experiment for finding the temperature of saturated steam at an absolute pressure of 7 lbs. per square inch.

21. Use Regnault's formula to calculate the total heat required to generate 1 lb. of steam at a temperature of 250° F. from water at 212° F.

22. Draw up a heat balance-sheet from the following data—

Lbs. of water evaporated per pound of coal, 8·5.
Temperature of feed, 60° F.
Temperature of steam, 360° F.
Lbs. of air used per pound of coal, 26.
Temperature of boiler-house, 80° F.
Temperature at base of chimney, 400° F.
Heating value of coal used, 14,000 Th. U. per pound.

23. What heat must be given to 1 lb. of water at 80° F. to convert it into steam at 303° F.? Regnault's formula for the total heat of a pound of steam from water at 32° F. being $H = 1082 + 0·305t$, where $t°$ F. is the temperature of the steam, how many pounds of this steam are equivalent in total heat to the calorific power (15,000 units of heat) of a pound of coal? (S. and A. 1898.)

24. One boiler produces 9 lbs. of dry steam at 402° F. from feed-water at 62° F., and another 10 lbs. of dry steam at 302° F. from feed-water at 110° F. per pound of the same fuel; compare these performances. (S. and A. 1899.)

CHAPTER X.

ENERGY.

55. Heat and Work.—It has long been a matter of common knowledge that heat may be produced by doing work as well as by combustion. Tinder was ignited by striking a flint centuries before matches were invented, and up to the present day South Sea Islanders light their fires by rubbing two sticks together. It was only sixty years ago, however, that people began to think of trying to find out whether a given amount of work would always produce the same quantity of heat. Dr. Joule, of Manchester, was the first to prove, by a series of experiments conducted between 1840 and 1849, that it would.

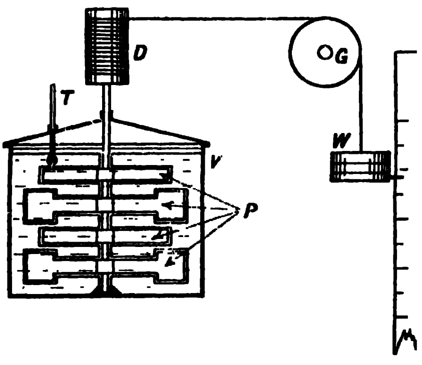


FIG. 96.—Dr. Joule's apparatus for determining the number of foot pounds of work equivalent to one thermal unit.

Joule's apparatus is shown diagrammatically in Fig. 96. All the refinements necessary to ensure accuracy are purposely omitted from this sketch. A weight *W* was attached to a string passing over a guide pulley *G* and

wound round a drum *D*. As *W* fell the drum rotated carrying with it a set of paddles *P* which passed between fixed plates in a vessel *V*, filled with water. These paddles churned up the water and, in so doing, absorbed the work done by the falling weight; there was consequently a rise in temperature which was measured by the thermometer *T*. The drum could be disconnected from its spindle to wind up the weight, so that the whole work done on the water was due to the descent of *W* and could, therefore, be easily determined in foot pounds.

The experiments showed that 772 foot pounds of work were absorbed for every thermal unit generated.

Since the time of Joule many other experimenters have worked at this same problem, and his estimate has been found to require a slight correction. **774 foot pounds of work per thermal unit** is the ratio now generally adopted. It is called **Joule's equivalent**, in memory of the pioneer investigator, and is frequently written as *J*.

Ex. 1.—A cyclist maintains a constant speed in descending a hill 300 feet high by applying his brake; his weight plus that of his machine amounts to 180 lbs.; how much heat is generated at the brake blocks?

The work done at the brake block in preventing an increase of speed is

$$300 \times 180 \text{ ft. lbs.}$$
$$= 54{,}000 \text{ ft. lbs.}$$

Since the whole of this work is converted into heat, the heat generated

$$= \frac{54{,}000}{774} \text{ Th. U}$$
$$= 70 \text{ Th. U. nearly.}$$

In an engine the heat of the steam is used to do work, and it has just been shown that this work will produce a definite quantity of heat.

The question naturally arises, "Did the same quantity of heat disappear in producing the work?" It did. This fact may be deduced from the results of any carefully conducted engine trial; for, if all the heat coming away from the cylinders, including that lost by radiation, as well as

that carried away in the exhaust steam, be subtracted from the heat brought into the cylinder in the live steam, the difference will be found to be one seven hundred and seventy-fourth ($\frac{1}{774}$) of the foot pounds of work done by the engine.

In other words the heat converted into work in the cylinder per minute

$$= \frac{I.H.P. \times 33{,}000}{774} \text{ Th. U.}$$
$$= I.H.P. \times 42{\cdot}6 \text{ Th. U.}$$

56. Heat Balance-Sheet for a Steam-Engine.—The discovery of this definite relation between heat and work laid the foundation of a sound theoretical knowledge of the action of the steam-engine and all other heat engines. It is of primary importance to the practical engineer, for it enables him to determine how much of the heat of his coal is usefully employed and how much is wasted; it enables him, in fact, to draw up a heat balance-sheet for his engine as well as for his boiler.

Ex. 2.—During an engine trial, lasting one hour, the average indicated horse-power was 30, the steam pressure in the valve chest was 75 lbs. per square inch, absolute, and any water mixed with the steam supply was drained away before reaching this point.

The exhaust steam, amounting to 800 lbs., was discharged at atmospheric pressure; it was condensed and cooled to a temperature of 112° F., in order to weigh it. In condensing and cooling it 16,000 lbs. of water were raised through a range of 45° F.

After the trial the slide-valve was removed and the exhaust-pipe stopped; steam was then turned on and the amount condensed in the cylinder per hour noted. This quantity, 88·8 lbs., may be taken as a measure of the heat lost by radiation under working conditions.

Draw up a balance-sheet from the results of this experiment.

To keep the numbers small it will be best to take one minute as the unit of time.

Referring to the first table in the Appendix we see that the total heat of one pound of steam at an absolute pressure of 69·21 lbs. per square inch is 1174·1 Th. U., while if the pressure is raised to 79·03 lbs. per square inch it is 1176·8 Th. U. We may therefore take the total heat of one pound of steam at 75 lbs. pressure absolute to be 1176 Th. U.

$\frac{800}{60}$ lbs. of such steam were supplied to the engine per minute.

∴ Heat supplied per minute

$$= \frac{800}{60} \times 1176$$
$$= 15{,}680 \text{ Th. U.}$$

The heat discharged in the exhaust steam is

$$\frac{16{,}000}{60} \times 45 + \frac{800}{60}(112 - 32) \text{ Th. U. per min.}$$
$$= 13{,}067 \text{ Th. U. per min.}$$

The latent heat of a pound of steam at 75 lbs. pressure per sq. inch, absolute, may be taken as $1176 - (307 - 32)$, *i. e.* 901 Th. U., since 307° F. is the boiling-point corresponding to that pressure.

∴ Heat lost by radiation per minute

$$= \frac{88{\cdot}8 \times 901}{60}$$
$$= 1334 \text{ Th. U. per min.}$$

Finally, the heat converted into work per minute

$$= \frac{30 \times 33{,}000}{774}$$
$$= 1279 \text{ Th. U. per min.}$$

The balance-sheet drawn up from these results will appear as follows—

	Th. U.		Th. U.
Heat supplied in steam per min.	15,680	Heat discharged in exhaust per min.	13,067
		Heat lost by radiation per min.	1,334
		Heat converted into work per min.	1,279
	15,680		15,680

The figures in the above example are fairly representative of what actually takes place, though they have been slightly adjusted to make them balance exactly. In practice, there is almost always a small difference between the measurements of the heat supplied and the heat discharged, owing to imperfections in the instruments used. This error can be eliminated by making a large number of trials.

57. Inefficiency of the Steam-Engine.—One most important point to notice is that out of 15,680 thermal units supplied to this simple engine only 1279 thermal units were converted into work, the bulk of the remainder being carried away in the exhaust steam.

It is difficult at first to see why all this heat had to be wasted. Perhaps a second example will make the reason plainer.

Imagine that heat is supplied to an iron column supporting a load. It will cause the metal to expand, and to do work in raising the load by the amount of its expansion. A quantity of heat represented by this work will disappear, but the rest will remain as heat to keep the column expanded, and this portion, from the point of view of doing work, is wasted.

Exactly the same thing occurs in the case of the steam-engine. Heat is used to expand the water into steam, and, though a small portion of this heat is converted into work during the expansion, the bulk of it must remain as heat to keep the steam expanded.

The very best steam plants constructed up to the present time can be run on a consumption of one pound of coal per indicated horse-power per hour. Since one horse-power corresponds to 42·6 thermal units per minute, this means

that they are capable of converting $\frac{42 \cdot 6 \times 60}{14{,}500}$, *i. e.* ·176 of the heat supplied to them into work. Fig. 97 has been drawn with the idea of impressing upon the reader, graphically, the manner in which the total energy of the coal would be accounted for in such a case.

In many factories the exhaust steam from the engine is made use of for warming pipes, cauldrons, etc., so that the heat in it is not really wasted; in locomotives and steamships this economy cannot be effected.

Readers who have no opportunity of testing a large engine, should now extend the experiments with the model suggested in Chapter I, by measuring the rate of combustion of spirit required to maintain a series of powers and plotting the results on squared paper; the percentage of the heat supplied converted into work may then be calculated; it will, of course, be extremely small.

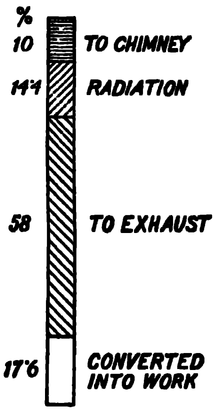


FIG. 97.—Distribution of the energy of each pound of coal in the most efficient steam plants constructed.

58. Energy.—It has been shown that, when materials enter into chemical combination, as during combustion, heat is liberated. This heat can be converted into work and the work stored up in a moving mass, as explained in the chapter on fly-wheels, or it can be used to generate electricity. Further, any of these processes can be reversed. Heat can be absorbed in breaking up a chemical compound, electricity in doing work, and work in producing heat.

It becomes evident from these statements that heat, work, electricity, etc., must really be different forms of the same thing, and this thing we call **Energy**.

In all the processes mentioned above energy merely changes its guise; it is neither created nor destroyed. It is in fact, as far as human experience goes, uncreatable and indestructible.

Unfortunately we have no common unit of energy. Heat is measured in thermal units, electricity in Board of Trade units, and work (on a large scale) in horse-power hours (one horse-power hour = 1,980,000 ft. lbs.). It is necessary for the student to learn the relation between these different ways of measuring energy, as a traveller, say, would have to learn the different ways of measuring distances in England (by miles), in France (by kilometres), and in Russia (by versts); he should therefore commit the following table to memory.

1 horse-power hour = 2558 thermal units.
1 Board of Trade unit = 3430 thermal units.
1 horse-power hour = 0·746 Board of Trade unit.

It is convenient to remember that one Board of Trade unit is approximately equivalent to $1\frac{1}{3}$ horse-power per hour.

It may interest the student to know that one 16-candle-power incandescent electric lamp absorbs ·06 Board of Trade unit per hour, and one arc light about ·6 Board of Trade unit per hour.

59. The nature of Heat.—No statement concerning the real nature of heat has, so far, been given, as it was thought better that the reader should commence his study of the subject experimentally. The phenomena discussed in this and the preceding chapter, and all others with which we are acquainted, can be explained as follows—

Every substance is supposed to be built up of innumerable minute particles, called *molecules*, which are the same throughout any one material, but different in different materials.[1] These are all in rapid motion to and fro, so that each keeps a small space open around it, as a man in a crowd might give himself breathing room by swaying violently backwards and forwards.

If heat is applied to a body, this motion, or vibration, becomes more rapid, the particles keep a larger space open around them, and so force each other further apart, thus

[1] We cannot say definitely what the size of a molecule is, but it must be so small that several millions will go to make up the cross-section of a hair.

causing the body to expand. If heat is removed on the other hand the vibration becomes less rapid, and the body contracts. If all the heat were removed from the body, the motion of its particles would cease. The temperature at which this would occur can be calculated, but it is so low ($-461°$ F., or $-273·7°$ C.) that it has never yet been reached experimentally.

The above theory explains very simply the similarity and interchangeability of work and heat. The former causes motion of a body as a whole; the latter sets each particle of a body in motion independently.

In Dr. Joules' experiment (see Fig. 96), for example, the falling of the weight and the revolution of the paddle as a whole were transformed into extra vibration of the particles of the water, as the work was changed into heat, *the amount of energy in the system remaining the same.*

It should be noted that, when a body, in expanding with heat, meets some external resistance, a portion of the energy of motion of its particles is taken up in overcoming that resistance, some of the heat given to the body being, in fact, converted into work.

A good example of the conversion of work into heat, and *vice versâ*, occurs when a gas, such as air, is compressed or expanded. The student will have noticed that, while he is inflating the tyres of his bicycle, the end of his inflator becomes hot. This happens because he is doing work in compressing air, and part of this work reappears as heat.

If compressed air does work in expanding, its temperature falls, because some of the energy in it is used up in overcoming the external resistance. Refrigerators act on this principle, the gas used being ammonia.

60. Adiabatic and Isothermal Expansion.—When a body expands (or is compressed) without heat being supplied to it (or removed from it) it is said to expand (or be compressed) *adiabatically*.

When heat is supplied (or removed) in order to keep the temperature constant, the expansion (or compression) is said to take place *isothermally*.

Boyle's law for permanent gases (see page 32) is only true for isothermal expansion. The pressure of a gas falls

more rapidly during adiabatic than during isothermal expansion, owing to the reduction of its temperature.

61. Relation between the Pressure, Volume, and Temperature of a Gas.—The relation which exists between the pressure and volume of a gas at constant temperature has already been stated in § 6, under the name of Boyle's law. An equally simple relation, first experimentally determined by Charles, exists between the temperature and volume of a gas at constant pressure.

A gas when heated at constant pressure, expands $\frac{1}{273\cdot 7}$ of its volume at 0° C. for each degree centigrade by which its temperature is raised.

Let V_0 and V be the volumes of a gas at temperatures 0° C. and t° C. respectively.

$$\text{Then } V = V_0 \frac{273\cdot 7 + t}{273\cdot 7}$$

$$\therefore \frac{V}{273\cdot 7 + t} = \text{a constant quantity.}$$

$$\text{Let } 273\cdot 7 + t = T.$$

Then T is called the **absolute temperature** of the gas.

$$\therefore \frac{V}{T} = \text{a constant.}$$

Let P = the absolute pressure of any gas.
V = its volume.
T = its absolute temperature.

By Boyle's law,

$$P\,V = \text{a constant, when } T \text{ is constant.}$$

By Charles' law,

$$\frac{V}{T} = \text{a constant, when } P \text{ is constant.}$$

$\therefore$ If P V and T all vary,

$$\frac{P\,V}{T} = \text{a constant} = R, \text{ say,}$$

$$\text{or } P\,V = R\,T$$

This relation is a most important one.

Ex. 3.—Coal-gas leaves a gas-works at 30° C., and 16 lbs. pressure per sq. inch absolute; it is supplied to the consumers at 15° C., and 15 lbs. pressure per sq. inch absolute. Find the change in volume per 1000 feet.

Let V = the final volume of the gas.
Then by the above equation

$$1000 \times 16 = R\,(30 + 273 \cdot 7) \quad . \quad . \quad . \quad (1)$$

and also

$$V \times 15 = R\,(15 + 273 \cdot 7) \quad . \quad . \quad . \quad (2)$$

dividing 2 by 1,

$$V \frac{15}{1000 \times 16} = \frac{288 \cdot 7}{303 \cdot 7}$$

$$\therefore V = 1000 \times \frac{288 \cdot 7 \times 16}{15 \times 303 \cdot 7}$$

$$= 1014 \text{ cubic feet}$$

∴ The gas increases in volume to the extent of 14 cubic feet per thousand cubic feet.

62. Entropy.—Heat will only pass from one body to another when the latter is at a lower temperature than the former.

Owing to this fact, it is convenient to be able to express not only the amount of heat that is given to a body during a certain operation, but also the temperature at which that heat is supplied. A suitable expression is obtained by dividing each portion of the heat received by the absolute temperature at which it is received, and summing the quotients.

This total is called, for short, the **change in entropy** of the body during the operation.

If H_1 H_2 H_3, etc., be quantities of heat received by the body at absolute temperatures T_1 T_2 T_3, etc., then—

The total change in the entropy of the body is

$$\frac{H_1}{T_1} + \frac{H_2}{T_2} + \frac{H_3}{T_3} + \; + \text{etc.}$$

The units in which entropy is measured are called ranks. When a body receives 1000 thermal units at an absolute temperature of 500° its entropy is increased by

$$1000 \div 500 = 2 \text{ ranks.}$$

It should be noted that there is no change in entropy during adiabatic expansion, just as there is no change in temperature during isothermal expansion.

EXAMPLES X.

1. What is meant by Joule's equivalent of heat?

2. How many foot pounds of work would be required to raise the temperature of one pound of water 11° C.?

3. In a landslip, 700 tons of earth descended 30 feet. Calculate the heat generated.

4. A brake is applied to the fly-wheel of an engine and absorbs 10 horse-power. How many thermal units are generated by it per minute?

5. On a certain steamer 1 ton of coal (calorific value 14,500) is burnt per hour when the engines are indicating 1,100 horse-power; what proportion of the energy in this coal is converted into work?

6. 1,200 lbs. of coal are burnt on a locomotive during a run of 60 miles, the average tractive force exerted being 2,000 lbs. What is the thermal efficiency of this engine?

7. The thermal efficiency of the engines and boilers of a steamer is ·12 when the indicated horse-power is 1,000; how many pounds of coal must be burnt per hour under these circumstances?

8. State your ideas as to the nature of heat, explaining briefly the phenomenon of change of volume with change of temperature.

9. What is the nature of the change which takes place when work is converted into heat?

10. Why cannot all the energy in one pound of coal be converted into work by using a steam-engine?

11. Why is a perpetual-motion machine an impossibility?

12. The following figures refer to a small electric-lighting plant. Show how the energy of each pound of fuel consumed is disposed of in this case—

Lbs. of coal burnt per hour	100
Heat equivalent of coal (Th. U.)	14,500
Lbs. of feed-water evaporated per hour	900
Temperature of feed	120° F.
,, ,, steam	360° F.
I.H.P. of engine	45
No. of 16 c.p. incandescent lamps supplied with electricity	500

13. Change into horse-power the rates of conversion of chemical energy by combustion of the following:—1 lb. of kerosene per hour; 1 cubic foot of coal-gas per hour; 1 cubic foot of Dowson-gas per hour; 1 lb. of coal per hour. The calorific powers are, in Fahrenheit pound heat units, 1 lb. of kerosene, 22,000; 1 lb. of coal, 15,000; 1 cubic foot of coal-gas, 700; 1 cubic foot of Dowson-gas, 100. (S. and A. 1899.)

14. Using the calorific powers given above, calculate the efficiencies of—

(*a*) A large, good condensing engine, using 2 lbs. of coal per brake-horse-power hour.

(*b*) A gas-engine using 26 cubic feet of coal-gas per brake-horse-power hour.

(*c*) The Diesel oil-engine, which is said to use 0·56 lb. of kerosene per brake-horse-power hour. (S. and A. 1899.)

15. When 6 cubic feet of air, measured at an absolute pressure of 15 lbs. per square inch, and a temperature of 140° C., are compressed to a volume of 1·7 cubic feet, the pressure rises to 75 lbs. per sq. inch absolute; what is the final temperature?

16. How much heat must be given to a mass of fluid at 150° C. to increase its entropy by 1·5 ranks, assuming that its temperature remains constant?

CHAPTER XI.

CONDENSING ENGINES.

63. Expansion of Steam below Atmospheric Pressure.— If the exhaust steam from an engine is discharged into the air, the back pressure on the piston must be at least 15 lbs. per square inch absolute, but if it be passed into a closed vessel and cooled rapidly, it will condense into water occupying, relatively, a very much smaller volume.

The condensation will go on till the back pressure is reduced to that of saturated steam at the temperature of the cooling vessel. For example, if this temperature is 140° F. the pressure will, according to the first table in the Appendix, be 2·88 lbs. per square inch.

The ratio of expansion of steam in an engine is limited by the back pressure, and can, therefore, be increased when a cooling vessel, or *condenser*, is used. It was explained in Chapter II, that this would lead to a smaller weight of steam being needed to do a given amount of work.

To make the matter quite clear, we will extend the example given on page 37. There we considered an engine working under the following conditions—

Area of piston A sq. inches;
Stroke of piston L feet;
Cut-off at $\frac{1}{4}$ stroke;
Release at end of stroke;
No compression;
Initial absolute steam pressure 60 lbs. per sq. inch;
Back pressure 15 lbs. per sq. inch absolute.

$BCPE$, Fig. 98, represents the indicator diagram for this engine. The mean effective pressure is 21 lbs. per sq. inch.

$\therefore$ Work done per stroke $= 21\,A\,L$ ft. lbs. . . . (1)

Here let us consider an engine similar in all respects to the above, except that it has a stroke of 4 L feet, and that cut-off occurs at $\frac{1}{16}$ of the stroke.

The same quantity of steam will be used in both cylinders for $\frac{1}{16}$ of 4 $L = \frac{1}{4} L$, but the final pressure in the second case will be $\frac{60}{16} = 3\frac{3}{4}$ lbs. per sq. inch, instead of 15 lbs. per sq. inch.

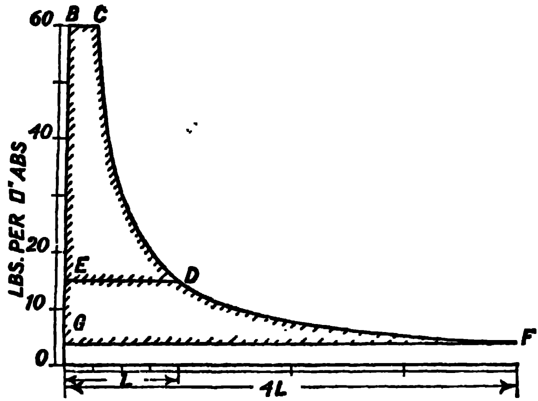


FIG. 98.

Suppose the steam to be condensed at this pressure, then the indicator diagram will be represented by $BCFG$, Fig. 98, and the mean effective pressure shown by this is 10·5 lbs. per square inch; therefore—

Work done per stroke

$$= 10{\cdot}5\,A \times 4\,L$$
$$= 42\,A\,L \text{ ft. lbs.} \quad . \quad . \quad . \quad (2)$$

It must be remembered that, though a greater amount of work is got out of each lb. of steam in case (2) than in case (1), a much larger engine has been used, which means a larger loss in friction of guides, journals, glands, etc.; and, further, a portion of the work gained must be expended in pumping the accumulation of water out of the condenser

against atmospheric pressure. These two considerations put a practical limit to the amount of expansion that can be used advantageously.

64. Condensers.—The simplest method of condensing steam is to spray a jet of cold water into an enlarged portion of the exhaust pipe; condensed steam and condensing water are then allowed to flow into a receiver, whence a pump, worked by the engine itself, discharges them into the air. This process is termed *jet-condensing*.

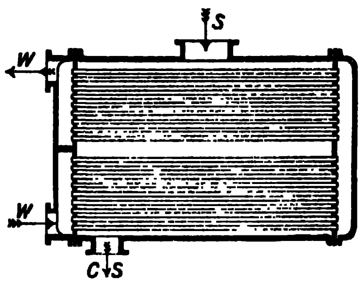


FIG. 99.—Surface condenser.

Where a large supply of pure water is not available, but sea water or foul water can be obtained, a surface condenser may be used. One of these is shown in Fig. 99. It consists of an outer casing containing a large number of thin brass tubes, through which water circulates in the direction indicated by the arrows marked *W*. Steam enters at *S*, and is condensed by coming into contact with the cold pipes. The water formed passes through the opening *C.S.* to the pump.

Surface condensers are invariably employed at sea, for they make it possible to collect the condensed steam and return it to the boiler as feed water.

The first steamships built were fitted with jet condensers so that sea water had to be used as feed water; as this was evaporated the salt it contained accumulated in the boilers, and had to be got rid of by partially emptying the latter at frequent intervals, a process which

entailed great loss of time and fuel. The surface condenser obviates this difficulty. It is only since its introduction that long, fast voyages have become practicable.

65. The Air-Pump.—Fig. 100 shows an air-pump for emptying the surface condenser of a marine engine. It is so named because it has to deal with a small quantity of air which is usually present in steam, as well as the water. If this were not continuously removed it would materially increase the back pressure in the cylinder.

V_1, V_2 and V_3 are three valves, formed of discs of rubber, called the head-valve (V_1), the bucket-valve (V_2), and the foot-valve (V_3). The foot-valve should be placed at least as low as the bottom of the condenser in order that the water may flow to it naturally. The bucket, or plunger, P, is of brass, bound round with hemp packing, or a brass spring ring, to make it air-tight. It is driven by a rocking lever from one of the cross-heads of the engine (see Fig. 114).

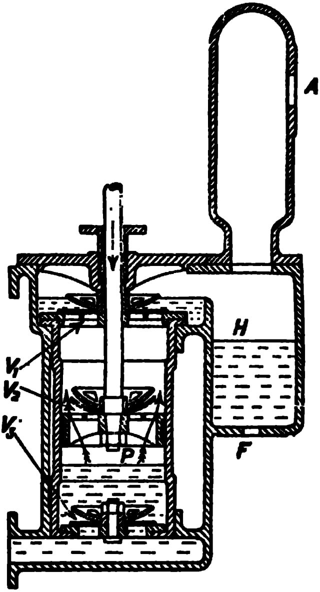


FIG. 100.—Air-pump of a marine engine.

On the up-stroke any water and air already above the piston pass through the valve V_1, and a fresh supply enters the pump-barrel through V_3.

On the down-stroke (shown in the figure) V_1 and V_3 are closed. As the plunger descends the pressure above it falls by expansion, and that below it increases till V_2 opens and allows air and water to pass it; these are trapped on the next up-stroke and discharged, the former escaping at A,

and the latter being led to the feed-tank by a pipe attached to the hot well H at F.

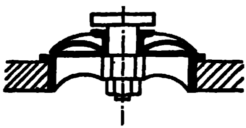


FIG. 101.—Bronze air-pump valve.

A group of 4 or 6 small bronze valves, shaped like inverted saucers, which rise and fall on a central pin, are often used in place of the large rubber discs described above. One of these is illustrated in Fig. 101.

66. Amount of Water required for Condensation.—Besides the air-pump a circulating pump, for dealing with the cooling water, has to be fitted to many condensing engines. This is similar in principle to a feed-pump, but it is much larger, and is usually made double-acting.

The quantity of injection water required to condense a given weight of steam in a jet condenser can be calculated, if the temperature and latent heat of the steam be known, for the heat gained by the former must equal that lost by the latter.

Ex. 1.—An engine discharges steam at $4\frac{1}{2}$ lbs. pressure absolute; determine how many pounds of injection water at 60° F. are required per lb. of steam. if the final temperature is not to exceed 100° F.

Let W = weight of injection water required.

Heat gained by injection water = W (100 − 60) Th. U. . . . (1)

Total heat of steam at $4\frac{1}{2}$ lbs. pressure absolute, reckoned from water at 32° F. = 1130 Th. U. (from tables).

Heat lost by steam per lb. = 1130 − (100 − 32) Th. U. . . . (2)

From (1) and (2)

$$W(100-60) = 1130 - (100-32).$$
$$\therefore W\,40 = 1062.$$
$$\therefore W = 26{\cdot}55 \text{ lbs.}$$

In surface condensers the circulating water has not time, during its passage through the tubes, to attain the temperature of the condensed steam, and therefore a rather larger quantity is necessary than is used in jet condensers.

67. The Oldest Form of Steam-Engine.—The first steam-engines made were all condensing engines, in fact their cylinders were merely allowed to fill with steam which was afterwards condensed to form a vacuum.

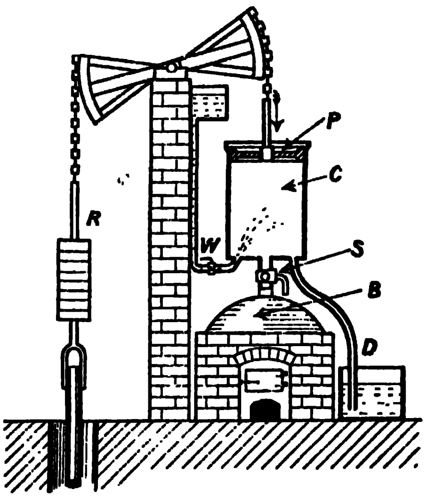


FIG. 102.—Newcomen's pumping engine.

B = boiler.
C = cylinder.
P = piston.
R = weighted pump-rod.
S = steam-valve.
W = water-valve.
D = drain-pipe.

Engineers at that period had neither the knowledge nor the materials necessary for constructing cylinders or boilers to withstand high pressures, and, since the engines were used to drive pumps in mines, there was always an unlimited supply of cooling water at hand.

The Newcomen engine, invented in 1705 by Thomas Newcomen, a blacksmith of Dartmouth, in conjunction

with Thomas Savery and John Cawley, is illustrated in Fig. 102.[1]

A cylinder *C* was placed above the boiler *B*, and a pipe containing the cock *S*, connected the two. The piston *P* was coupled to one end of a beam, to the other end of which the pump was attached by the rod and chain *R*. This rod was loaded to make it heavier than the piston.

Cold water could be injected into the cylinder by opening the cock *W*; and the pipe *D*, in which a non-return valve was placed, formed a drain leading to the boiler-feed tank.

In starting the engine the cylinder was filled with steam, cock *S* was then closed and *W* opened. The jet of water introduced condensed the steam and formed a vacuum, the pressure of the atmosphere on the top of the piston was thus left unbalanced, and was sufficient to force the latter down and raise the pump-plunger. On closing *W* and opening *S* the pressures on the two sides of the piston were again equalised, and the out-stroke was accomplished by the rods falling back into their original position.

The constant attention of an experienced engine-driver was at first necessary, as both cocks had to be worked by hand; but later (in 1713) a rod hung from the beam was made to perform these operations automatically by means of tappets clamped to it in suitable positions.

As might be expected, these engines used a large amount of steam to do a comparatively small amount of work.

68. Inventions of James Watt.—In 1763 James Watt, an instrument maker, was engaged to repair a model of Newcomen's engine belonging to Glasgow University. This turned his attention to the possibilities of steam as a source of power, and, becoming interested in the matter, he made a series of careful experiments, which led him to the following conclusions. The reader should study these carefully, for they cover almost the whole economic theory of the steam-engine.

[1] At least one engine of this type was still in regular use ten years ago. A model may be seen at work in the Victoria and Albert Museum, South Kensington.

(1) That much of the steam used in the Newcomen engine was condensed during the out-stroke of the piston in warming the cylinder-walls, and was therefore wasted.

(2) That this waste could be avoided by keeping the cylinder as hot as the steam entering it.

(3) That, to allow of this, a separate vessel should be used for condensing.

(4) That the colder this vessel was the better the vacuum would be.

(5) That steam could be used at high pressure, and made to do work by expansion without using a condenser.

Watt embodied these discoveries in an application for a patent made 1769, in which he also proposed the use of a steam-jacket, to prevent cylinder condensation, and of a pump to prevent any accumulation of air in the cylinder.[1] On obtaining his patent he commenced manufacturing engines (still single-acting and working at low pressures without expansion) which proved so efficient that they were not only employed for pumping, but were able to compete successfully with the windmills and water-wheels formerly used for driving machinery. Further experience enabled him to make further improvements. He added the governor, made the cylinder double-acting, introduced the slide-valve (the invention of his assistant Murdock), and so forth; other inventors also appeared in the field, and the steam-engine gradually approached the form in which we have it to-day. It was not, however, till 1800 that any considerable raising of the steam pressure was attempted, and this process led, during the latter part of the last century, to alterations which will be discussed in the next chapter.

While dealing with the history of steam power it will be interesting to notice the coal consumption required by the

[1] Much of Watt's apparatus is preserved in South Kensington Museum. It is worth a visit, for, apart from its historic interest, it shows what valuable researches may be carried out with simple tools and inexpensive materials.

best plants constructed at various stages in its development, and for this purpose the following table has been compiled.

Date.	Type of engine and boiler.	Pounds of coal burnt per B.H.P. per hour.
1720	Newcomen engine	40 to 50
1813	Watt pumping engine, Cornish boiler.	12
1844	Improved single-acting pumping engine and Cornish boiler . . .	$3\frac{1}{2}$
1895	Triple expansion marine engine and boiler working at 200 lbs. pressure.	$1\frac{1}{2}$
1906	Turbine with superheated steam . .	$1\frac{1}{8}$

EXAMPLES XI.

1. Distinguish between a jet condenser and a surface condenser. Why is the latter always fitted on sea-going ships?

2. State briefly the advantages of a condensing over a non-condensing engine.

3. What is the function of an air-pump? Why are three sets of valves used?

4. Sketch a single-acting air-pump, indicating the position of the valves during the up-stroke.

5. In a marine engine trace the path of the steam between the low-pressure piston and the boiler feed-tank.

6. What additional parts are required in order to convert a non-condensing into a condensing engine? Under what circumstances is it better to use a condensing engine? When is it necessary to use a surface condenser? How is a surface condenser constructed? (S. and A. 1899.)

7. If the temperature of the condensing water supplied to a jet condenser be 62° F., and the water is pumped out of the hot well at a temperature of 106° F., and the steam to be condensed enters the condenser at a temperature of 212° F., what weight of injection water would be required per pound of steam condensed? (S. and A. 1896.)

8. In a jet condenser 24 lbs. of water at 52° F. are injected for each pound of steam at 212° F. to be condensed; what will be the final temperature of the mixture?

9. In the above example what would be the final temperature of the mixture if the steam were at 176° F. initially?

10. Ten pounds of steam at 158° F., and 280 lbs. of water at 62° F. enter a surface condenser per minute; at what temperature will the former leave, if the latter leaves at 99° F.?

11. In Fig. 97, 58 % of the heat of each pound of coal (heating value 14,500) was represented as being discharged into the condenser; assuming that the whole of this was carried away by the circulating water, how many pounds of the latter must have been used per pound of coal if its rise in temperature was 40° F.?

12. In a 1,000 H.-P. engine 10 % of the energy of the coal is converted into work, and 60 % is discharged in the circulating water; how many tons of the latter must be passed through the condenser per hour, allowing a rise in temperature of 30°?

13. Sketch a Newcomen engine, and point out some reasons for its inefficiency.

14. The piston of a Newcomen engine is 4 feet in diameter; calculate the effective pressure upon it during the down-stroke, if the cylinder is cooled by injection to 158° F., and the atmospheric pressure is 15 lbs. per sq. inch.

15. Enumerate the chief discoveries made by Watt in connection with the action of steam.

16. Why were Watt's engines more economical than those of Newcomen?

CHAPTER XII.

CONDENSATION AND LEAKAGE OF STEAM IN THE CYLINDER.

69. Action of Cylinder Walls.—James Watt fully realised the importance of preventing the steam, when entering an engine cylinder, from being condensed before it had time to do any work. He succeeded in reducing this condensation to reasonable limits, by using a steam-jacket, but he was unable to stop it altogether.

The exhaust steam must be at a lower pressure, and therefore at a lower temperature, than the incoming steam. The cylinder walls are naturally cooled by the former while it is in contact with them, and the next supply of live steam partially wastes itself in re-heating them. The greater the difference between the initial and exhaust pressures of the steam the greater this amount of "*initial condensation*" will be.

Watt used steam at about 10 lbs. pressure per square inch, the temperature of which would be 240° F.; the exhaust temperature in his engines was probably 120° F. (corresponding to a back pressure of $1\frac{3}{4}$ lbs. per square inch, absolute); he had, therefore, to deal with a range of temperature of 120°. In modern engines a range from 390° F. (at 200 lbs. pressure) to 120° F. has to be faced. Hence the prejudicial cooling action of the cylinder walls is greater, unless proper precautions are taken, in these days of high pressures than formerly.

70. Leakage.—A second source of loss is the leakage of steam past the piston and slide-valve direct to the exhaust-port. This loss is difficult to distinguish from that due to condensation. It increases with the range of pressure used in the engine, and also with the range of temperature, as a valve may be distorted by unequal expansion.

To give the reader some idea of the effects of these two losses it may be stated that, at the point of cut-off, in the cylinder of a small simple engine, only two-thirds to three-quarters of the feed water supplied is present as steam, the remainder is either present in the form of water, or has leaked into the exhaust pipe.

Five common methods of dealing with the above difficulties are discussed below; the most important of these is the method of compounding, which is given last.

71. Effect of the Steam-Jacket, Increase of Speed, and Separate Inlet and Exhaust Ports.—(*a*) **The steam-jacket** was fully described in Chapter I. It is of considerable use in slow-running engines. It keeps the cylinder walls so hot that no water condenses upon them; this is of great value, since dry metallic surfaces absorb and give up heat much more slowly than moist ones.

(*b*) **Increase of Speed.**—The time occupied by each stroke in high-speed engines may be made so short that before the cylinder metal has time to take up much heat from the incoming steam the temperature of the latter will have fallen (by its expansion) to that of the exhaust. Leakage also forms a smaller portion of the total steam consumption at high speeds. An increase of speed will, therefore, lead to economy, other things being equal.

(*c*) **Separate Steam and Exhaust Ports.**—If an arrangement of ports similar to that shown in Fig. 18, page 30, but with mechanically-driven valves such as will be described on page 177 is adopted, the admission passages will not have to pass exhaust steam; they will, therefore, remain at a high temperature and induce but little condensation. Corliss and Sulzer engines owe part of their excellent economy to the use of four independent valves.

72. The use of Superheated Steam.—To superheat steam it is passed, after leaving the boiler, through a superheater, consisting of a series of tubes placed over or near to the furnace; here its temperature is raised without increasing its pressure, and it can afterwards part with the additional heat thus supplied to it, before any of it condenses; when,

therefore, it comes in contact with cylinder walls cooler than itself it does not immediately cover them with moisture, as saturated steam would do, but leaves them dry, so that they absorb heat less rapidly from it than from the latter.

73. Compounding.—The amount of condensation and leakage depends upon the range of temperature pressure in the cylinder. In a simple engine this must be from boiler to exhaust temperature; if, however, we carry out the first portion of the expansion of the steam in a small cylinder, and discharge it thence, at an intermediate pressure, into the main cylinder to complete the process, we divide this range of temperature into two portions. The hottest steam will then come in contact with surfaces reduced to the intermediate temperature only, and the amount of it wasted by condensation will be proportionately reduced, and, further, the steam which leaks past one cylinder may be usefully employed in the next. Such an engine is called a *compound engine;* the small cylinder is called the *high-pressure*, and the large one the *low-pressure* cylinder.

When condensing engines are driven by high-pressure

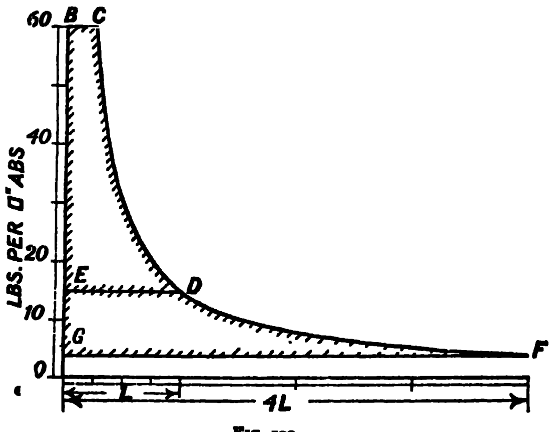


FIG. 103.

steam it is found to be worth while to divide the difference of temperature between three cylinders, and even quadruple expansion is sometimes used in special cases.

A simple example will make the principle of successive expansions quite plain.

To save work, we will take the same data as those given on page 158, though the maximum pressure dealt with there is rather smaller.

Fig. 103, which is an exact copy of Fig. 98, represents the indicator diagram of an engine taking steam at 60 lbs. pressure, absolute, for $\frac{1}{16}$ of its stroke, and discharging it at $3\frac{3}{4}$ lbs. pressure, absolute.

The temperature of saturated steam at 60 lbs. pressure is $292\frac{1}{2}°$ F., and at $3\frac{3}{4}$ lbs. pressure it is $150\frac{1}{2}°$ F., therefore the range in temperature is 142° F.

Suppose *N*, Fig. 104, represents this engine diagrammatically, and suppose that, fitted to the same crank-shaft, there is another engine, *M*, of quarter the stroke and with a piston of the same area. If now, instead of supplying steam direct to *N*, the same quantity is passed into *M*, the cut-off in the latter must occur at quarter-stroke, and therefore its exhaust pressure is $\frac{60}{4} = 15$ lbs. The corresponding exhaust temperature is 212° F., so that the range in *M* is only $80\frac{1}{2}°$ F. *BCDE*, Fig. 103, represents the indicator diagram for *M*.

If engine *N* is made to cut off at quarter-stroke, and the exhaust steam from *M* supplied to it, its indicator diagram will be represented by *E D F G*. The back pressure in it will still be $3\frac{3}{4}$ lbs., so that its range of temperature is reduced to $61\frac{1}{2}°$ F.

[These temperatures are only approximate, as the simple rule used in calculating the pressures is not quite true for saturated steam.]

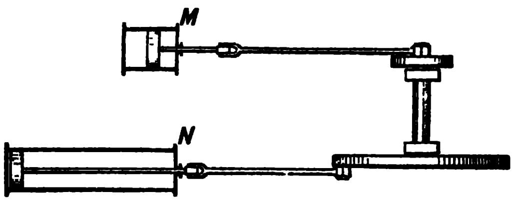


FIG. 104.

It is evident that the same work is now done in the two cylinders as was previously done in *N* alone. There has been no gain in this direction; the economy is effected by reducing the initial condensation, and this does not directly affect the indicator.

On referring to the calculations on page 159, it will be seen that area *BCDE*, Fig. 103 = $\frac{1}{2}$ area *BCFG*, and is, therefore, equal to area *FDFG*; so that the work done in each cylinder is the same.

74. The design of Compound Engines.—To simplify the conception as far as possible, we have first considered a double-expansion engine in which the pistons have the same area, but different strokes. The conclusions arrived at will, however, apply equally well if the pistons have the same stroke, but different areas. The latter is much the most convenient arrangement in practice, for the total force on each piston will then be about the same, and similar rods, glands, guides, cranks, etc., can be used for both.

Fig. 105 shows two cross-sections of a pair of cylinders for a horizontal compound engine. These are 13 inches and $22\frac{1}{2}$ inches in diameter. The ratio of their cross-sections is, therefore, 1 to 3. The high-pressure piston is shown at one end of its stroke, and the low-pressure piston, in its corresponding position, is nearly at half-stroke. Live steam is just entering the back end of the high-pressure

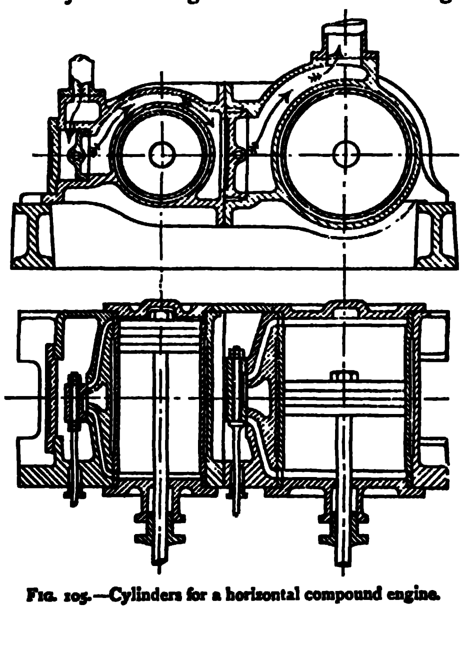


FIG. 105.—Cylinders for a horizontal compound engine.

cylinder, and the exhaust steam from its front end is passing to the low-pressure steam-chest, whence it is being admitted to the front end of the low-pressure cylinder. The exhaust steam from the back end of the low-pressure cylinder is at the same time escaping to the exhaust pipe.

The passage between the two cylinders is made large enough to form a *receiver* in which steam can collect, without any serious rise in pressure, during the interval between the closing of one low-pressure steam-port and the opening of the other.

The mechanical efficiency of a compound engine is of necessity lower than that of one with a single cylinder, because there is the friction of two sets of pistons, glands, guides, etc., to overcome; and this loss may, in extreme cases, overshadow the saving effected in steam consumption per indicated horse-power. Generally speaking, the simple engine is best for pressures up to 60 lbs., the compound for pressures up to 120 lbs., and the triple for all higher pressures.

EXAMPLES XII.

1. State, from your knowledge of energy, why the exhaust steam in an engine must be at a lower temperature than the incoming steam.

2. The steam cylinder of a small pump is 4″ in diameter, and the piston makes 180 strokes 4″ long per minute. Saturated steam at 60 lbs. pressure, by gauge, is admitted during the whole of each stroke. What weight of steam would be used per hour if there were no losses?

(The volume of 1 lb. of saturated steam, at 75 lbs. pressure per square inch, absolute, is 5·88 cubic feet.)

3. The above pump actually uses 95 lbs. of steam per hour. Account for the balance.

4. What becomes of the water in an engine cylinder during exhaust?

5. Why did Watt's invention of the condenser effect a great economy? Why does condensation take place in the cylinders of modern engines, and how do we attempt to get rid of it? (S. and A. 1897.)

6. What does the use of a steam-jacket accomplish, and why is it most effective on a slow-running engine?

7. Why would you expect a high-speed engine to be more economical than a slow-speed one if both were unjacketed?

8. State shortly why superheating, steam-jacketing, and successive expansions are now being used in steam-engines. (S. and A. 1899.)

9. A compound engine has cylinders 32" and 60" in diameter, steam is cut off in the high-pressure cylinder at $\frac{5}{8}$ of the stroke; what is the ratio of expansion?

10. Of two engines to work under the same conditions and with the same ratio of expansion, one with a single cylinder, and one compound, which would you consider it best to purchase? Give reasons for your answer.

11. The boiler pressure in a locomotive is 180 lbs. (by gauge), and the exhaust pressure is 5 lbs. above atmosphere; compare the range of temperature in its cylinders with that in a marine engine working between the pressures of 130 lbs., and − 12 lbs. by gauge.

12. Show, by referring to question 11, why locomotives are made on the compound, and marine engines on the triple-expansion principle.

13. A triple-expansion engine has cylinders 40", 60", and 96" in diameter. If the high-pressure valve cuts off at half-stroke, calculate the total ratio of expansion.

14. The stroke of the above engine is 4' 6", and the mean effective pressures on the three pistons during a certain trial were 59·0, 27·1 and 10·5 lbs. per square inch when the shaft was making 80 revolutions per minute. What horse-power was being developed in each cylinder?

15. Sketch a section of the cylinders of any compound engine, and trace the path of the steam through them.

16. What are the objections to using the same passage for admitting steam to an engine and allowing it to escape?

CHAPTER XIII.

MODERN STATIONARY ENGINES AND STEAM TURBINES.

75. Development of the Steam Engine.—It would be impossible, even if it were advisable, to give in this volume anything approaching a full description of the various forms in which the steam-engine is now built. The student must acquire his knowledge of these by personal observation, if that knowledge is to be of service to him. He must keep his eyes open when he has to travel by steamer or wait at a railway terminus, when he passes through a workshop or visits an exhibition of machinery; the brief notes given here may assist him in understanding what he then sees, but that is all they can do for him.

In Chapter XI. the early history of the steam-engine was traced up to the introduction of the slide-valve and the admission of live steam at both ends of the cylinder.

The beam, which had been a necessity in pumping-engines, was long retained in those built for driving a crank-shaft; probably because it was feared that the cylinder and glands would wear oval from the weight of the piston, if placed horizontally.

Trevithick made a locomotive and boiler, to work at high pressure without condensation, as early as 1803; but he lacked both the means and the perseverance necessary to push his inventions. Other engineers of that time were not bold enough to follow his lead, as pressures of more than 20 to 30 lbs. per square inch were considered excessively dangerous; they were, in fact, adopted in America many years before their general introduction in England.

With the advent of high-pressure steam an imperfection of the simple slide-valve became apparent. It cannot be arranged to cut off steam much before half-stroke without causing considerable wire-drawing. When a shorter period of admission was required some more complicated device had to be introduced, such as Meyer's expansion gear, illustrated in Fig. 106. This consists of two valves sliding over one another and moved by independent eccentrics; the first of these has steam ports passing right through it, and the second is arranged to cut off steam by covering the

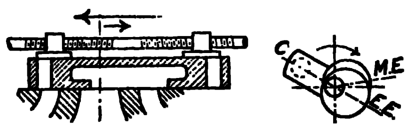


FIG. 106.—Meyer's expansion gear.

latter early in the stroke. All the other operations are performed by the first valve in the ordinary way.

Fig. 106 shows the gear as it would place itself at the point of cut-off on the out-stroke; the arrows represent to scale the speeds at which the two valves are then moving, and the sketch at the side indicates the corresponding positions of the crank *C*, the main eccentric *M E*, and the expansion eccentric *E E*.

The action can be completely studied with the model of Fig. 49 by adding an additional eccentric disc above the original one. The travel of both valves may be made the same, and the angle of advance of the second eccentric 90°.

The expansion valve is usually made in two parts mounted on right and left-handed screws; so that, by simply rotating its spindle, the lap can be varied and the point of cut-off changed.

A better, but more expensive way of obtaining a large ratio of expansion is to return to the old practice of having separate valves for admission and exhaust, at each end of the cylinder. The first-named are opened by rods worked from an eccentric. They are released with a trigger and are

instantly closed by the pressure of a strong spring. Steam can thus be cut off sharply at one-tenth or even one-sixteenth of the stroke.

The point of the stroke at which the trigger is drawn is regulated by the governor, so that the power of the engine is reduced by increasing the ratio of expansion.

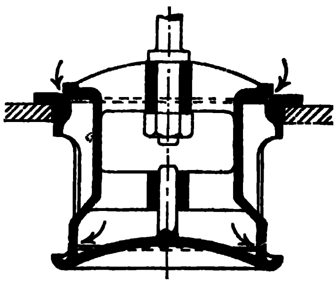


FIG. 107.—Double-beat valve.

In engines of the Corliss type the valves are in the form of segments of a cylinder, and they are rotated by an external crank-arm to uncover the ports; in those built by Messrs. Sulzer of Winterthur (Switzerland), and by Messrs. Robey & Co. of Lincoln, double-beat mushroom valves are employed. Fig. 107 is a section of one of these; it is hollow, and when closed it rests on two conical faces of as nearly as possible the same diameter. The object of this arrangement is to minimise the force required to open the valve against pressure.

Let A_1 = area of top seat.
A_2 = area of bottom seat.
p_B = boiler pressure.
p_C = pressure in cylinder.
W = weight of valve.

Then

downward pressure on valve $= (A_1 - A_2)p_B$.
upward pressure on valve $= (A_1 - A_2)p_C$.

∴ Force required to lift valve

$$= (A_1 - A_2)p_B - (A_1 - A_2)p_C + W.$$
$$= (A_1 - A_2)(p_B - p_C) + W.$$

This can be made small by making $A_1 - A_2$ small.

76. The introduction of the Compound Engine.—During the early part of last century the amount of machinery to be driven in the mills of Lancashire and elsewhere naturally increased from year to year, till at last a point was reached, when the power demanded of the existing engines was more than they could supply, and larger ones had to be erected in their place.

In 1845, however, Mr. McNaught introduced the novel idea of meeting the difficulty by merely raising the boiler pressure employed and using the steam to drive the piston of an additional but smaller cylinder, before supplying it, at the old boiler pressure, to the original valve-chest. Not only was more power obtained by this means, but it was found that actually less steam was required *per horse-power* than before. The economy was so marked that, though the reasons for it were probably not fully understood at the time, builders began to construct new engines on this compound principle, and these proved so successful that it became the standard type for condensing engines, both on shore and at sea, till improvements in the materials obtainable for boiler-making rendered a further raising of steam pressures possible, when the compound was in its turn replaced by the triple-expansion system.

The plan of expanding steam by passing it through two cylinders of different sizes was first introduced by Hornblower in 1781; but it then proved a failure, as the range of pressure used was not sufficient to bring out its advantages and compensate for the additional cost of construction.

77. The Steam Turbine.—During the last years of the nineteenth century the **steam turbine** became a commercial success.

When made on a large scale, it compares favourably as regards steam consumption with the best reciprocating

engines, while it occupies less space and requires less attention. It has the further advantage of applying a perfectly uniform turning moment to the shaft which it drives, and, for this reason, it is being largely introduced into electric lighting stations. Its compactness, its small weight, and its perfect balance are also leading to its adoption for propelling ships.

The principle on which the turbine works is extremely simple, and was applied to a model more than 2,000 years ago, but very serious difficulties had to be overcome before it could be made use of economically.

The simplest form of turbine is that invented by Count de Laval, and this will therefore be described first, though it is only made in small sizes.

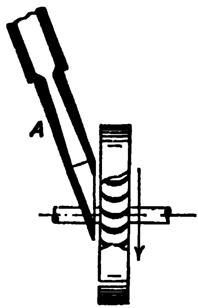


FIG. 108—Nozzle and vanes of a Laval steam turbine.

78. The Laval Turbine.—In the de Laval turbine, see Fig. 108, high-pressure steam is allowed to flow through one or more nozzles, *A*, into a chamber connected with a condenser and air-pump. The steam does no work on any other body in this process, and therefore it must use up the energy set free in accelerating itself. The nozzle is so designed that all the particles of steam are accelerated uniformly and at the exit a steady jet is formed having a velocity of from 10 *to* 30 *miles per minute* according to the initial pressure. This jet impinges upon curved, shrouded

vanes fixed to the rim of a solid disc mounted on the driving shaft of the turbine. In passing through the passages between these vanes the direction of motion of the steam is changed, and as a consequence it applies a thrust to the disc which causes the latter to rotate.

The sides of the passages are made parallel so that the relative velocity of the steam passing through them shall remain constant. To accomplish this the back of one vane is made concentric with the face of the next.

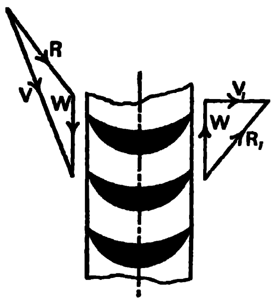


FIG. 109.

The action of the steam and the principle upon which the curvature of the vanes is fixed will be made clear in Fig. 109. V represents, to some small scale, the direction and rate of motion of the steam jet, which, on leaving the nozzle, makes an angle of from 17 to 20 degrees with the disc. W represents the velocity at which the passages move past the jet. Therefore R represents the velocity of the jet relative to the passages. In order that the jet may enter the passages with as little disturbance as possible the tips of the vanes must point in the direction R.

$R_1 = R$ (see above) represents the relative velocity of the steam on leaving the vanes. Combining this with W, the velocity of the wheel, we get V_1 the final absolute velocity of the steam towards the condenser, which is of necessity wasted.

The energy of a moving body was shown on page 92 to vary as the square of its velocity; therefore the proportion of energy wasted is $V_1^2 \div V^2$ or about $\frac{1}{5}$.

It is obvious from the figure that the velocity of the rim of the disc must be nearly half that of the jet. The driving shaft must therefore rotate at a very high speed (say 10,000 revolutions per minute for a wheel one foot in diameter); the vane wheel is consequently made of the strongest steel obtainable to withstand the centrifugal forces set up in it, and the shaft upon which it is mounted is made long and flexible so that it may adjust itself to run steadily like a spinning-top.

It is generally necessary to reduce the speed in the ratio of at least ten to one by toothed wheels before the power of this turbine can be usefully applied even for electrical purposes.

The steam supply to the nozzles is controlled by a governor and throttle valve, acting in the same way as that described on page 95.

79. The Rateau and Curtis Turbines.—The main problem to be solved in designing large turbines is to make full use of the great velocity which steam acquires in passing as a jet from a high to a low pressure without using abnormal speeds of rotation.

In the *Rateau turbine* the difficulty is overcome by dividing the drop of pressure into a number of stages. Thus a Rateau turbine consists virtually of fifteen or more Laval turbines placed in series on the same shaft. At the high-pressure end admission to each chamber, from the previous chamber, takes place through groups of tapered passages corresponding to nozzles. The diameter of the discs and the number and size of the passages increases towards the low-pressure end in proportion to the increase in volume of the steam.

This design is simple and convenient, but it entails an enclosed, steam-tight bearing between each pair of vane wheels.

In the *Curtis turbine* only four to six chambers are used. In each chamber there are two or three sets of moving vanes, with rings of vanes fixed to the casing between them.

Fig. 110 shows the fixed (black) and the moving passages in the first chamber. On the right of the figure the corresponding diagrams of velocities for the steam are drawn. The speed of the vane wheel is less than it would be in a Laval turbine, consequently the steam leaves the first set of moving vanes with a considerable backward velocity V_1, which is changed in direction by the fixed vanes, and made use of in the second set of moving vanes. The second and

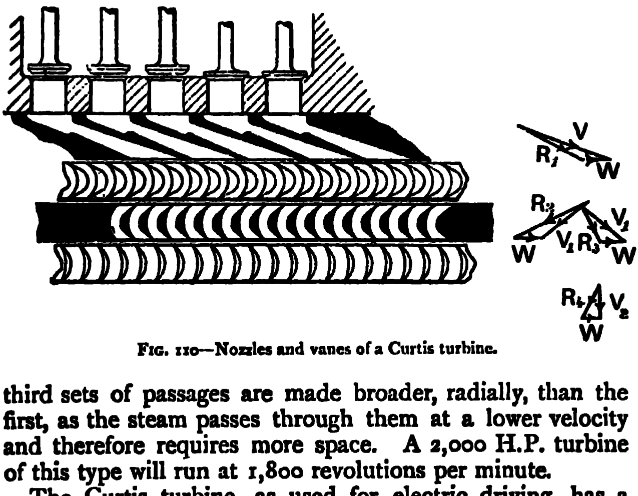


FIG. 110—Nozzles and vanes of a Curtis turbine.

third sets of passages are made broader, radially, than the first, as the steam passes through them at a lower velocity and therefore requires more space. A 2,000 H.P. turbine of this type will run at 1,800 revolutions per minute.

The Curtis turbine, as used for electric driving, has a vertical shaft, and the weight of the revolving parts is borne by a broad collar under which a constant supply of oil is forced, at high pressure, by a pump. The dynamo is placed above the turbine and the condenser immediately below it. The governor acts by closing a greater or smaller number of the first ring of nozzles by means of the valves shown in Fig. 110.

80. The Parsons Turbine.—In the *Parsons turbine* (Figs. 111 and 112) there are a large number of complete rings of fixed and moving passages. The moving passages are tapered as well as the fixed ones, so that they all form nozzles in which an increase in relative velocity, and a corresponding drop in pressure, occurs. Thus the energy of motion of the steam is produced and absorbed gradually, and speed of rotation of the vane drum can is kept within reasonable limits, while the intermediate bearings of the Rateau and Curtis turbines are avoided.

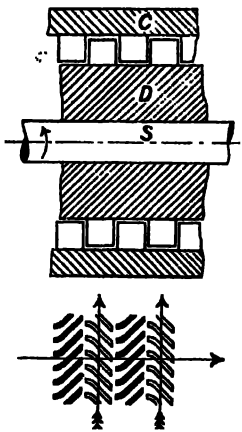


FIG. 111.—Portion of the drum and vanes of a Parsons' steam turbine.

Since there is a drop in pressure at every ring of vanes it is obvious that all the passages must be kept full of steam and that the clearances between the vanes and the casing or drum must be made very small to prevent serious leakage. These conditions are not essential in the turbines previously described.

Fig. 111 shows diagrammatically the construction of a Parsons turbine. *S* is the shaft, *D* the vane drum, and *C* the casing. The forms of the fixed (black) and moving vanes are sketched below, and these should be compared with Fig. 110. An arrow indicates the general direction of flow of the steam.

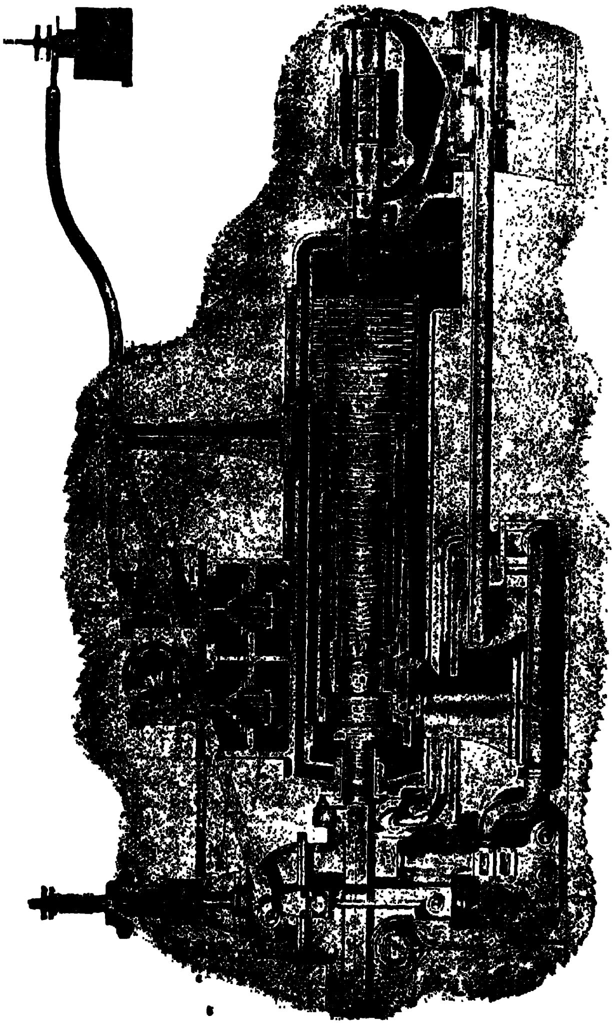


FIG. 112.—Longitudinal section of a Parsons' steam turbine.

Fig. 112 is a sectional elevation of a complete Parsons turbine. Steam is admitted through a double-beat valve in a series of puffs, the duration of which is regulated by the governor; it enters the casing at *A* and passes through 48 rings of moving vanes to the exhaust pipe. These rings are made in increasing sizes to allow for the increasing volume of the steam as its pressure falls.

The rings *B*, *C*, *D* are solid and run in grooves. The system of passages here shown is so arranged that the difference of pressure on the two sides of each set of these "dummies" is the same as the difference of pressure between the two sides of the sets of vanes of similar diameter; and therefore the longitudinal pressure of the steam on the former balances that on the latter.

In a marine turbine the thrust of the propeller along the shaft makes most of the dummies unnecessary.

A small lubricating pump, and the air-pump, when there is one, are driven at a reduced speed through a worm and wheel.

As an example of the Parsons turbine the machinery of the steamship *King Edward* may be quoted.[1]

This is estimated to develop 4,000 horse-power at a speed of 20 knots, and yet it is smaller and weighs less than the ordinary paddle engines of the sister ship *Duchess of Hamilton*, which travels at 18 knots only. It consists of a central high-pressure turbine running at 700 revolutions per minute, receiving steam at 150 lbs. pressure, and discharging it at 30 lbs. pressure into two parallel low-pressure turbines, driving separate shafts, making 1,000 revolutions per minute.

In all turbines, owing to the high speeds necessarily used, there is a considerable loss of power in friction between the driving discs, or drums, and the atmosphere of steam in which they rotate. This loss increases rapidly with the density and pressure of the steam, hence turbines are not at all economical when working as non-condensing engines, and only become efficient when a high vacuum is used.

[1] The *King Edward* was the first passenger steamer to be fitted with turbine machinery.

EXAMPLES XIII.

1. What inventions do we connect with the names of Hornblower, Trevithick and Meyer?

2. Describe, from your own observation, some form of trip-gear for giving an early cut-off without wire-drawing.

3. Sketch an expansion valve and state its use.

4. Can an engine be reversed with Stephenson's link-motion when it is fitted with an expansion valve the eccentric for which is set opposite the crank?

5. Describe and sketch the construction of a double-beat or equilibrium valve. When and for what purpose are such valves used? In such a valve the two seats measure respectively 8 inches and $7\frac{1}{2}$ inches in diameter, and the weight of the valve is 70 lbs. What pressure per square inch would cause the valve to lift, the pressure between the valve discs being disregarded? (S. and A. 1896.)

6. What was the chief difficulty to be overcome in making the steam turbine a practically useful machine?

7. Describe briefly the working of a Parsons' steam turbine.

8. Small turbine engines have to make a greater number of revolutions per minute than large ones to work efficiently; why is this?

9. Why must a Laval turbine run much faster than a Parsons' turbine?

10. Describe the bearing at the low-pressure end of any turbine to which you have access, or of which you can find a full account in one of the technical papers.

11. 240 lbs. of steam per hour issue from the nozzles of a Laval turbine with a velocity of 2,500 feet per second. What horse-power would this represent if all the energy of motion were available?

CHAPTER XIV.

MARINE ENGINES AND BOILERS AND LOCOMOTIVES.

81. Application of the Steam-Engine to the Propulsion of Ships.—It is essential that marine engines shall be capable of running continuously for days or weeks together; they must, therefore, be simple in construction, easy to lubricate, and, when a breakdown does occur, repairable with a minimum amount of labour.

Not only is economy in working of importance, but, in addition, the total weight of the machinery and boilers required to generate a given power must be reduced as far as possible in order to increase the cargo and passenger-carrying capacity of the ship and the speed at which she can be driven. It is in this direction that future improvements are likely to be made.

The first successful steamer was the *Charlotte Dundas*, a small vessel employed as a tug on the Forth and Clyde Canal in 1802. She had one paddle-wheel at the stern driven directly by a horizontal condensing engine not differing greatly from those of small power now used for the same purpose. Unfortunately she raised such large waves in the narrow channels through which she had to pass that the canal company, fearing damage to the banks, prohibited her use after a few months.

The first steam-propelled passenger service was established in America in 1807. The vessel employed was, however, fitted with engines supplied from England. She plied between New York and Albany, covering that distance, 150 miles, in 32 hours.

In 1812 the *Comet*,[1] built by Henry Bell, commenced running on the Clyde between Glasgow and Greenock, and by 1820 there were 34 steamers at work in British waters. These were all paddle boats and were mostly driven by a modification of the beam engine; to save height, two beams were used, placed low down, one at each side of the cylinder, coupled to a single connecting-rod below the crank at the one end and to a pair of rods descending from a long cross-head at the other.

The ordinary beam was, and is still, largely used on river steamers in America, but in Europe both forms have given place to a direct-acting compound engine with two cylinders inclined diagonally upwards from the floor of the ship towards the shaft.

To work satisfactorily paddle-wheels must only have a small portion of their diameter immersed. For this reason their use has been abandoned in large sea-going ships, the draught of which must vary greatly according to the amount of cargo and coal they have on board. The screw-propeller, invented somewhat later, is employed instead.

The screw-propeller may be described as consisting of portions of the three or four threads of an abnormally deeply-cut three or four threaded screw. The boss from which these project is mounted on a horizontal shaft, passing through the stern-post as far below the water-line as possible.

When the propeller is rotated, it tends to travel through the water carrying the ship with it. If the resistance of the vessel were negligible it would move forward one pitch length each revolution, as if it were turning in a solid nut. If, on the other hand, the resistance were very great, no forward motion could take place, but the water would be driven astern. All practical cases must be intermediate between these two extremes.

A properly proportioned propeller will give a ship with fine lines a forward motion twelve times as great as the backward motion which

[1] The engine of the *Comet* is now preserved in South Kensington Museum.

it imparts to the water. The energy used in setting the water in motion is, of course, lost. There is a further loss due to friction on both faces of the screw-blades as they move edgewise through the water. As a rule, one-third of the indicated horse-power of the engines is usefully employed, one-sixth is disposed of in friction of glands, bearings, etc., and the remainder is absorbed in the ways mentioned above. Similar losses occur with paddle-wheels and even with oars.

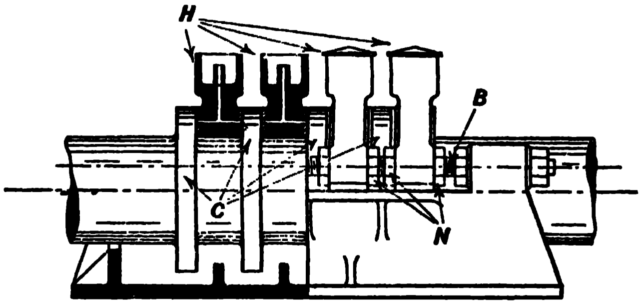


FIG. 112A.—Thrust-block of a screw steamer.

The force along a rotating screw-shaft has to be transmitted to the hull of the vessel by a thrust-block bolted firmly to the framing, and this, if not correctly designed, will give a great deal of trouble. In the best form (see Fig. 112A) a series of collars, *C*, are turned on the shaft, and between these horseshoe-shaped pieces, *H*, are inserted. These pieces transmit the pressure upon them to the frame, along the large bolts, *B*, which pass through notches on either side of the shoes. By means of nuts, *N*, the shoes can be adjusted singly or all together. They can also be removed in turn for examination while the shaft is rotating.

82. The Modern Marine Engine.—The triple expansion engine is now the standard type for screw steamers; the cylinders are inverted and supported over the crank-shaft by cast-iron frames at the back—which also form the crosshead guides—and cast-iron or forged steel pillars at the front.

Each crank is usually a separate forging supported on a pair of bearings of its own, and coupled to its neighbours through flanges at its ends. As all the cranks are similar, an accident to any one of them is provided against by carrying a single spare section.

With three cranks set at 120° to each other the resultant turning moment is fairly uniform, and the want of balance in the moving parts is not sufficient to set up serious vibrations at ordinary speeds. A better arrangement still is obtained by using two low-pressure cylinders instead of one, so as to have four cranks, with which a perfect balance can be obtained as regards the principal forces called into play.

The condenser casing is cast in one piece with two or more of the frames.

The air-pump and the boiler feed-pump are driven from a rocking lever, resembling the old-fashioned beam, coupled by short links to the low-pressure cross-head. The circulating pump for supplying cooling water to the condenser may be driven in the same way, or by a small auxiliary steam plant.

The general arrangement of a large marine engine capable of developing 6,000 horse-power is outlined in Fig. 114. The low-pressure and intermediate cylinders are shown fitted with double-ported slide valves, and the high-pressure cylinder with a piston valve to reduce the friction.

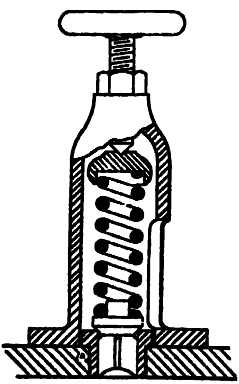


FIG. 113.—Cylinder relief valve.

In rough weather a considerable amount of priming may take place, and, to prevent water carried into the cylinders from doing serious damage by being driven against their ends, relief valves which will open automatically are fitted to each cover.

One of these is shown in Fig. 113. It consists of a small spring-loaded safety valve, the blowing-off pressure of which can be regulated with a hand-wheel.

An example of the use of the

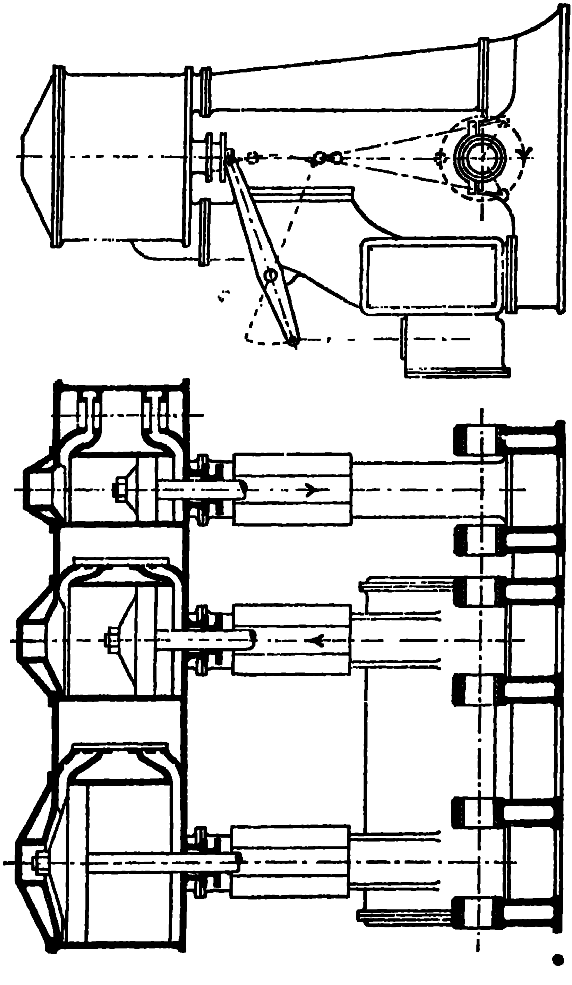


FIG. 114.—Outline drawing of a 6,000 I.H.P. marine engine.

steam turbine on board ship was quoted in the previous chapter.

83. The Marine Boiler.—The draught of air through the fire-bars of a marine boiler is now usually increased, or *forced*, with a fan; a rate of combustion of 30 to 40 lbs. of coal per square foot of grate per hour, or twice what is common in Lancashire boilers, can thus be maintained. This means that smaller furnaces can be used to provide a given power, and the consequent saving in weight more than compensates for any slight falling off in efficiency.

The Scotch boiler (see Fig. 115), is the standard type used in the merchant service at the present time. It consists of a large cylindrical shell, with flat ends supported by longitudinal stays, and contains 1, 2, 3, 4, or 5 internal furnaces, *F*, according to its size. These furnaces are lap-welded tubes. They are corrugated in order to strengthen them and also to give them a certain amount of elasticity, to allow for unequal expansion. They should be designed so that they can be withdrawn without disturbing the rest of the boiler, as they are among the first parts to require renewal. Each one opens into a separate combustion chamber, *C*, from which the hot gases flow through a number of small tubes, *T*, to the uptake, *U*, leading to the funnel. Some of the tubes have nuts on their ends and serve as stays.

The combustion chambers are held together and supported at the back and sides by a great number of small stays screwed in and riveted over, or held with lock nuts. Their tops have to be made rigid in themselves by being bolted to cross girders as shown. (These will be again referred to in connection with locomotive boilers, see Fig. 124.)

The boilers for large vessels frequently have furnaces at both ends, each pair of which may open into a common combustion chamber.

84. Water-tube Boilers.—Boilers in which the water and steam circulate through small tubes surrounded by the

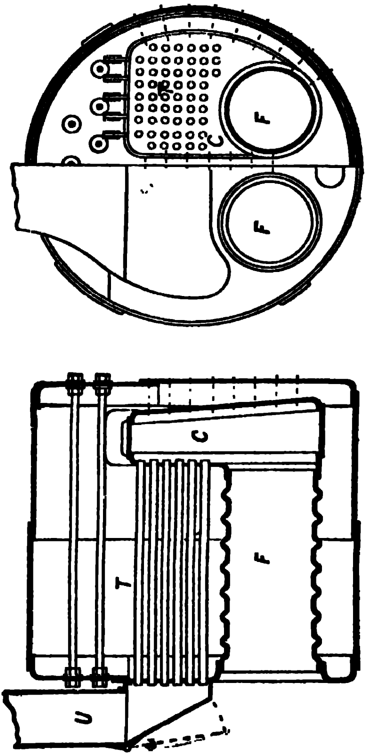


FIG. 115.—Scotch type of marine boiler.

F, F = furnaces.
C = combustion chamber.
T = tubes.
U = uptake.

products of combustion, are now becoming common both at sea and on shore. Their chief recommendation is that steam can be very quickly raised in them. They can also be made lighter for the same power than the older type. They are, however, more liable to serious leakage.

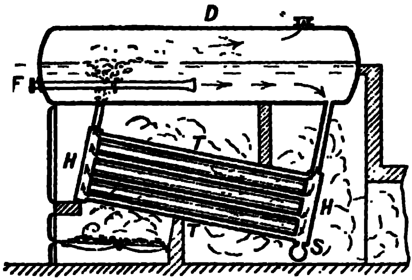


FIG. 116.—Babcock Wilcox water-tube boiler.

The best known water-tube boiler is that made by Messrs. Babcock and Wilcox. Two designs are used, one for working on land and the other on board ship. The former, being the simpler, is sketched in Fig. 116. It consists essentially of a number of inclined tubes, *T*, among which the furnace gases circulate; these communicate, through two groups of "headers," *H*, *H*, of square cross-section, with a steam drum *D*. The feed water is injected horizontally at *F*. It descends the back headers and is partially turned into steam in the lower tubes. This steam tends to rise towards the front headers and draws the remainder of the water with it back into the drum, so that a rapid circulation is maintained.

The process may be demonstrated experimentally with a model made of a thin metal drum and a single set of large glass tubes.

S is a cross drum placed below the "down-comers" to catch any sediment formed. The tubes are made accessible for cleaning by removing small "mud doors" placed opposite the ends of each.

In the marine pattern of the boiler the drum is placed at right angles to the furnace, and secondary sets of horizontal tubes, opening into vertical headers, take, as far as possible, the place of the fire-brick setting used in the land type.

The Belleville boiler, see Fig. 117, has been fitted on board many ships in the navy. In it the feed water descends

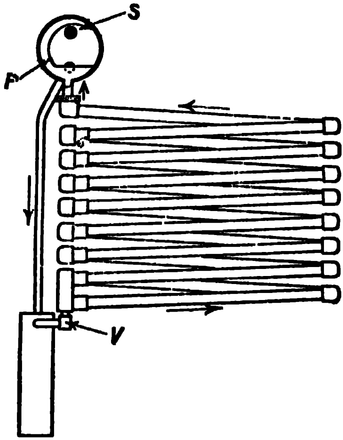


FIG. 117.—One element of a Belleville boiler.

a vertical down-comer, outside the furnace, at the foot of which a vessel is placed to catch the sediment; it is then admitted, through a non-return valve, *V*, into several sets of tubes which pass backwards and forwards over the whole length of the furnace, and discharge into a top drum *D*. Here a dash plate, *P*, causes the mixture of water and steam impinging upon it to rotate; the former, owing to its greater density, flies outwards, and the latter can be collected in a dry state from a central pipe *S*.

For small, fast vessels, such as destroyers, the Yarrow and the Thorneycroft boilers have been most successful. Fig. 118 is a section of the Yarrow boiler. It consists of one upper drum and two lower ones, connected by banks of straight tubes. The furnace is between the lower drums.

The water and steam circulate upwards through the hottest inner tubes, and downwards through the outer tubes which are not quite so hot.

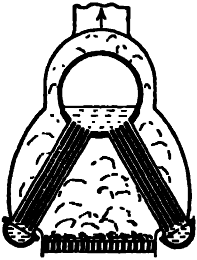


FIG. 118.—Section of a Yarrow boiler.

The Thorneycroft boiler is similar to the Yarrow except for the fact that its tubes are curved and discharge into the upper part of the drum, above the water-line, and that outside downcomers are used to aid circulation.

85. Locomotive Engines.—As reliability and economy in working are the key-words to marine engine design, so compactness and quick control are the guiding principles in planning a locomotive.

The minimum height of bridges is, in this country, 14 feet, and the space between the platforms for a single line is 9 feet, the distance between the rails being 4 feet 8½ inches. In building an engine whose size is limited by these gauges and which must, nevertheless, be capable of developing over 1,000 horse-power, economy of fuel becomes of secondary importance. High pressures have to be used with small ratios of expansion, and an extremely rapid rate of combustion is maintained in the furnace by using the exhaust steam to create a strong draught up the chimney.

The first public railway on which steam traction was employed was opened in 1829 between Manchester and Liverpool. It was worked with locomotives supplied by George and Robert Stephenson, the first of which, "The Rocket," easily defeated three other competitors in a competition arranged by the promoters of the line.

The first public railway was between Stockton and Darlington; but the trains upon it were drawn by horses till after the Lancashire line was opened.

A steam locomotive known as "Puffing Billy" was used on a private colliery line in Northumberland from 1813 onwards.[1]

---

[1] "The Rocket" and "Puffing Billy" are now in South Kensington Museum. Some other historic engines are to be seen at Newcastle and Darlington railway stations.

The special features of the Stephensons' early engines, notably the link-motion reversing gear (see Fig. 53), the tubulous boiler, and the steam blast are still maintained, but the form and arrangement of the parts have been much improved

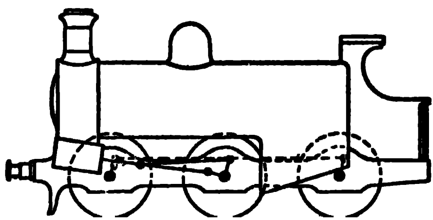


FIG. 119.—Goods locomotive.

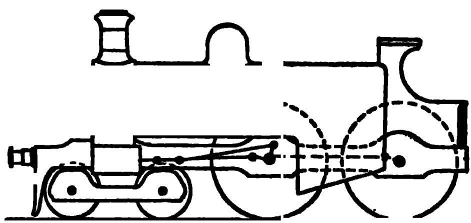


FIG. 120.—Passenger locomotive.

Fig. 119 is an outline sketch of a modern English goods engine. It is built up of two strong longitudinal frames with cross pieces at intervals. The ends of the boiler rest on these, and the axle boxes slide in guides bolted to them. There are three pairs of wheels, all of the same diameter, coupled together by coupling-rods, so that each takes a share in driving. The rods are jointed to allow for inequalities in the track. The two cylinders are placed at the front of the engine. They are raised above the centre line of the wheels to clear the front axle, and drive backwards on to two cranks at right angles, formed in the second axle.

The above arrangement of wheels is found to be too rigid to run round curves safely at very high speeds. In passenger

engines (Fig. 120) the forward end of the frames is carried on a separate four-wheeled truck called a "bogie," which is allowed a slight lateral and rotary motion; when this is deflected out of the straight line it slightly raises the front of the engine so that more weight is thrown upon it, and it is less liable to jump the rails. The four remaining coupled wheels are made larger than in a goods engine, to allow of a higher speed being maintained with the same piston velocity.

The tractive force which a locomotive can exert depends upon the friction between its driving-wheels and the rails. This amounts to one-sixth or one-seventh of the total load on the former.

A goods engine weighing 50 tons can exert a tractive force of

$$50 \div 6 = 8{\cdot}33 \text{ tons.}$$

In a passenger engine of the same weight only 36 tons would be supported by the coupled wheels, and its maximum possible tractive force would be

$$36 \div 6 = 6 \text{ tons.}$$

It is only at starting, or on steep gradients that the whole of these forces are called into play.

Compound locomotives were for a long time looked upon with disfavour in spite of their marked economy, as they took longer than simple engines to get up speed. They are now coming into general use for large powers. Two- and three-cylinder compounds are used, but the four-cylinder type is the most successful owing to the perfect balance of working parts which can be obtained with it. A sketch plan of a German locomotive working on that system is given in Fig. 121. There are two inside high-pressure cylinders driving two cranks at right angles in the driving axle; and two outside low-pressure cylinders driving crank-pins, set opposite to the high-pressure cranks, in the corresponding wheels.

A single valve gear is used to regulate the steam supply to each pair of high and low pressure cylinders.

The student should refer to *The Engineer*, *Engineering*, and other technical papers for detailed drawings of the most recent types of British and Foreign Locomotives.

86. The Locomotive Boiler.—The locomotive boiler has had to be designed to fit the space available for it. It is not, therefore, of the best form to resist internal pressures, and a large amount of staying is neccssary.

Fig. 122 shows one fitted with a Belpaire fire-box, as adopted by the leading railway companies. An outline section of this (without the stays) is given in Fig. 123.

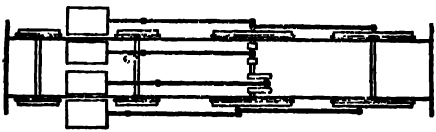


FIG. 121.—Plan of a four-cylinder compound locomotive.

An internal chamber, *F*, of copper in this country, but of steel in American practice, is surrounded by an outer shell of similar form. The two are connected through a forged iron foundation ring, *R*, and their flat surfaces are held together by numerous stays; the shorter ones (not shown) are copper bars screwed in and riveted over, the longer ones are shouldered steel bolts, with nuts on the outside, bearing on large washers.

A cylindrical shell protrudes from the outer fire-box, and a large number of flue tubes pass through this, from the inner fire-box to the front tube plate, where they open into a smoke-box, *M*, on the top of which the chimney is placed.

These tubes are fixed by expanding their ends with small rollers, and ferrules are driven into them to protect them from the flames.

The fire-door is formed by flanging the plates as shown.

An ash-pan with movable doors to regulate the draught is placed below the fire-bars, and a brick arch, *B*, supposted on cast-iron bearers is built over the back of the furnace to distribute the heat.

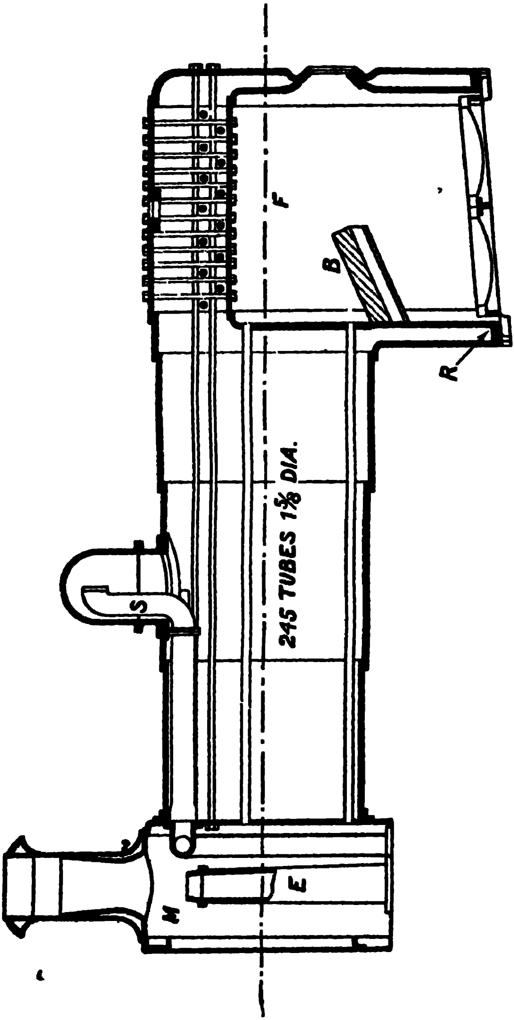


Fig. 122.—Locomotive boiler with Belpaire fire-box.

F = Fire-box. S = Steam-pipe.
M = Smoke-box. E = Exhaust-pipe.

A steam dome is placed on the top of the boiler from which the main steam-pipe, *S*, is carried forwards through the smoke-box to the steam-chest. The exhaust steam-pipe, *E*, passes through the smoke-box also. It is contracted at the top, and discharges below the chimney, causing an upward draught so strong that cinders and small pieces of coal are often drawn through the tubes. A jet of live steam is used to create a draught before starting.

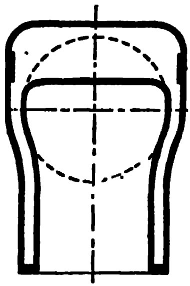


FIG. 123.—Cross-section of a Belpaire fire-box.

In the older, and still more common type of boiler, the outer fire-box is rounded at the top to the same radius as the shell. The crown of the inner box has then to be stiffened with girder stays (see Fig. 124), which are supported by links hung from transverse angle irons.

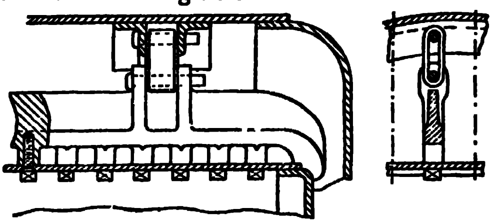


FIG. 124.—Section and elevation of one half of a girder stay for a locomotive fire-box.

The supply of feed water is carried in a tender or in side tanks. It is forced into the boiler by an injector and passes through an internal pipe leading to the centre of the water space in the shell.

EXAMPLES XIV.

1. Why has the screw replaced paddle-wheels for propelling large vessels?

2. Sketch the crank and thrust-shaft of a triple expansion marine engine.

3. What is the use of a thrust-block? How is it adjusted for wear?

4. A thrust of 5,000 pounds is required to propel a certain vessel at a speed of 5 knots; calculate the effective horse-power (E.H.P.) and the indicated horse-power (I.H.P.), assuming that, in this case, the latter is related to the former by the equation

$$I.H.P. = 55 + 1{\cdot}6\ E.H.P.$$

(1 knot = 6,086 feet per hour.)

5. Plot, on squared paper, curves representing the variation of thrust, effective horse-power, and indicated horse-power when the above vessel is driven at speed between 5 and 10 knots.

At these speeds the resistance of the ship will vary as the square of its velocity.

6. Sketch a cylinder relief valve and describe its use.

7. Why has a Scotch boiler a much larger ratio of heating surface to grate area than a Lancashire boiler?

8. Sketch one furnace tube of a marine boiler, and show how it is attached to the combustion chamber and front plate.

9. What must be the total area of the furnaces of a Scotch boiler in order to supply steam to a triple expansion engine of 600 I.H.P.? Steam consumption of engine, 15 lbs. per I.H.P. per hour; evaporative power of coal, 8 lbs. of water per pound of coal; rate of combustion, 30 lbs. of coal per square foot of grate per hour.

10. Sketch a Belleville water-tube boiler and describe its action.

11. Why are locomotives worked without condensation?

12. Explain the difference in design between passenger and goods engines.

13. The total weight on the driving wheels of a locomotive is 30 tons; what is the maximum tractive force it can exert? (Coefficient of friction $\frac{1}{6}$.)

14. If, in the above engine, the two pistons are 20″ diameter, and have strokes of 24″, and the driving wheels are 7′0″ in diameter, find the greatest mean effective pressure which can be employed.

(NOTE.—Equate work done on pistons to work done on draw-bar.)

15. Calculate the mean piston speed in the above engine when running at 60 miles per hour.

16. Why does a four-cylinder locomotive run more steadily than a two-cylinder one?

17. Sketch in outline a locomotive boiler and indicate the position of the safety valve, the steam regulator, and the feed check valve.

18. Sketch two forms of locomotive fire-box, and describe how each is stayed.

19. Why did the introduction of the blast-pipe in the chimney of "The 'Rocket" place it so far ahead of its competitors?

20. Sketch in position in the frame and describe any construction of axle-box of a locomotive engine with which you are acquainted, and show the arrangement of the springs. (S. and A. 1899.)

CHAPTER XV.

FUELS FOR INTERNAL COMBUSTION ENGINES.

87. Gaseous and Liquid Fuels.—In an ordinary steam plant, 10 to 15 per cent. of the heat of the coal passes up the chimney, and another 10 per cent. is usually lost by radiation between the boiler and the cylinder.

There is thus an absolute waste of one quarter of the available energy. This loss is in addition to the loss which is by the laws of thermodynamics inevitable in heat engines; the highest possible efficiency that a heat engine can have is $\frac{T_1 - T_0}{T_1}$, where T_1 and T_0 are the absolute maximum and minimum temperatures.

By carrying on the combustion within the engine, and using the resulting hot gases themselves as the working agent, a large portion of this loss can be avoided. In addition, the range of temperature in the cylinder will be much extended, which renders it possible to convert a larger portion of the heat energy produced into work.

Unfortunately, serious mechanical difficulties have to be overcome before coal can be so utilised, even when it is reduced to powder, but liquid and gaseous fuels can readily be used in this manner. Chief among these are :—

Petrol.—This consists of the more volatile part of the petroleum found in America, Russia, and elsewhere. It evaporates so readily, that air passing over or through it becomes saturated with its vapour, and a gaseous, explosive mixture is formed. In spite of the consequent danger attending its use, its portability makes it invaluable for motor-cars, launches, etc.

Paraffin is the heavier liquid portion of natural or mineral oil. It has a heat equivalent of about 19,000 thermal units (B.Th.U.) per pound. It burns readily, but is so much less volatile than petrol that hot chambers have to be used for vaporising it.

Lighting Gas.—This is prepared by the distillation of coal in a retort. It is a mixture of various gases composed of hydrogen and carbon, and varies considerably in heating value; 650 thermal units (B.Th.U.) per cubic foot may be taken as a rough average. The bulk of the carbon in the coal remains in the retort as coke. Coal gas is distributed throughout almost every town for lighting and heating. It is, therefore, easily obtainable, but is somewhat expensive.

The following figures give the composition of coal gas in three towns:—

Percentage by volume.	London [Society of Arts Trial].	Leeds [Tested by Grover].	Kilmarnock [Tested by Kennedy].
Marsh Gas, CH_4	37·34	41·78	42·80
Olefines, $C_n H_{2n}$	3·77	2·77	5·55
Hydrogen, H	50·44	39·11	43·60
Carbon Monoxide, CO	3·96	8·22	4·30
Nitrogen, N	3·98	8·00	2·70
Carbon Dioxide (CO_2), with traces of Oxygen (O)	0·51	0·12	5·35

The production of coal gas from one ton of coal varies from 10,000 to 11,000 cubic feet.

Producer Gas is prepared from coal, with as little waste as possible, for the special purpose of generating power. A common form of this is the Dowson Gas described below.

Mond Gas is produced by blowing into the producer a large excess of steam with the object of recovering the largest possible amount of ammonia from the fuel.

An average percentage analysis by volume of Mond gas is:—

Hydrogen	27·5
Marsh Gas	2·0
Carbon Monoxide	11·0
Carbon Dioxide	16·5
Nitrogen	43·0

Its calorific value is about 160 B.Th.U. per cubic foot.

Water Gas is obtained by passing steam over incandescent coke, and has a calorific value of about 400 B.Th.U. per cubic foot. An average percentage composition by volume is as follows :—

Hydrogen	49·17
Marsh Gas	·31
Carbon Monoxide	43·75
Carbon Dioxide	2·71
Nitrogen	4·06
	100

Blast Furnace Gas is the gas given off during the manufacture of pig-iron, and is very similar to ordinary producer gas, but it has a lower calorific value of about 100 B.Th.U. per cubic foot. Except that the lower calorific value requires higher compression and special means for ignition, blast furnace gas is well adapted for use in gas-engines, and is often used at smelting works to drive the blowing engines and to generate the electric power.

A typical percentage composition by volume from a coke-fed furnace is :—

Carbon Dioxide	11·39
Carbon Monoxide	28·61
Hydrogen	2·74
Hydrocarbons	·20
Nitrogen	57·06
	100·00

Acetylene Gas is not at present used largely for gas-engines, chiefly on account of its extra cost; further experiments and improved methods of production may in time render it more suitable for the purpose.

Reduction to Standard.—It must be remembered that for purposes of comparison all figures relating to gas consumption should be reduced to a standard pressure of 14·7 lbs. per sq. in. and a temperature of 32° F. This may be done as follows :—

Let B = Barometer pressure in inches.
W = Water pressure in inches of gas in meter.
T = Temperature °F. of gas in meter.
F = Factor by which gas consumption is to be multiplied to bring it to standard.

Then $$F = \frac{(\cdot 491\,B + \cdot 0361\,W)\,(32 + 461)}{14\cdot 7\,(T + 461)}.$$

This is an application of the law of gases, given on p. 154, that $\frac{PV}{T}$ = a constant.

88. The Gas Producer.—It was stated on page 127 that when coal is burnt in an insufficient supply of air carbon monoxide gas is formed, and only $\frac{3}{10}$ of the possible heat developed. The remaining $\frac{7}{10}$ can be obtained on burning the carbon monoxide to carbon dioxide.

A very simple producer may be made which will convert coal to carbon monoxide, and this gas may be used in a gas-engine, but such a plant could not have an efficiency of more than 70 per cent., or about that of a good boiler.

If steam is mixed with the air supplied to a carbon monoxide producer it also will react upon the carbon in the coal, and will produce hydrogen, and a further supply of carbon monoxide. This reaction absorbs heat from the fire instead of generating it, and therefore the steam supply must be carefully regulated or combustion will cease.

The idea of combining the above simple reactions is due to Mr. J. E. Dowson.

The composition of the gas produced when just enough steam is supplied to absorb the heat generated by the air is as follows:—

GAS.	*Volume per cent.*
Nitrogen (residue from air)	45
Carbon monoxide	39
Hydrogen	16
	100

It usually differs somewhat from this in practice. The average heating value obtained is 130 thermal units

(B.Th.U.) per cubic foot. This is much lower than that of lighting gas, owing to the large amount of inert nitrogen present.

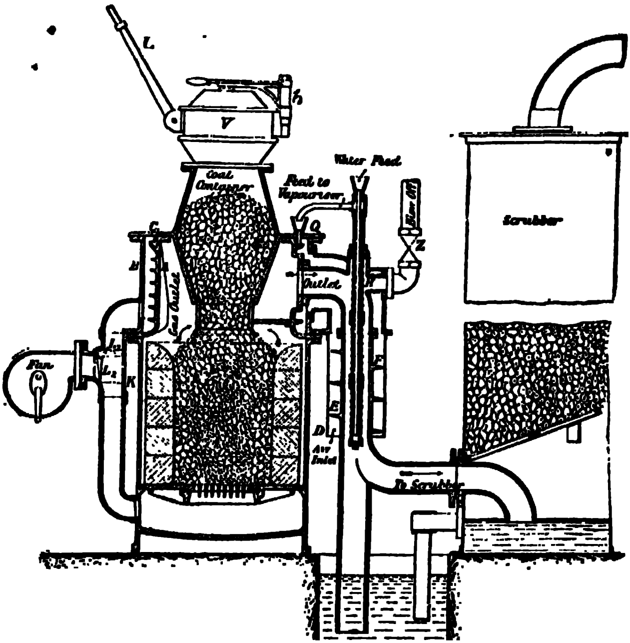


FIG. 124A.—Suction gas producer made by the National Gas-Engine Company.

A producer for a 20 B.H.P. gas engine is illustrated in Fig. 124A.[1] It consists of a vertical cast-iron cylinder, lined with fire-brick, and filled with fuel through a double-doored hopper, *V*. The suction of the engine itself makes a sufficient draft through this fuel to maintain combustion.

[1] This drawing is reproduced from *Engineering*. For further illustrations of this and other similar plants see Vol. lxxxi., page 817.

The hot gases pass along the gas outlet and through a scrubber filled with coke on their way to the engine. A small quantity of water is continuously sprayed over this coke to cool the gases and to free them from the dust they carry with them.

For safety, in case of an explosion in either the scrubber or the producer, a branch pipe is added which is sealed merely by immersion in a pit filled with the water overflowing from the scrubber.

Some of the heat in the gases leaving the fire is regained by using them to warm the air supply, which is drawn through the spiral chamber *E* surrounding the gas outlet, and thence passes round the hot upper part of the producer to the fire-bars, through the pipe *K*.

The feed water abstracts a further quantity of waste heat from the gases as it circulates through the double tube *H* inserted in the outlet pipe. The supply to this tube is adjusted by hand, and the overflow passes into the vaporiser, where it trickles down a series of channels *A* till it is all evaporated. The steam generated mixes immediately with the air mentioned above and passes with it down the pipe *K* to the fire.

When starting the fire, a positive draught has to be created with a hand-driven fan. The pipe *K* is closed by moving the flap L_2 into the position L_1, and a blow-off, cock *Z*, is opened, through which the first products of combustion escape. As the fire gets hot, carbon monoxide is generated and steam begins to form in the vaporiser. The gas may be tested at a small jet fitted for that purpose, and, when it will burn freely with a reddish flame, the engine may be started, the blow-off cock closed, and the fan stopped. The whole process occupies from ten to fifteen minutes.

In simple suction producers like the above only coke or anthracite coal, which consists of nearly pure carbon, can be used. The ordinary, cheaper coals cake and choke the fire, or produce tar, which clogs the valves and piston of the engine.

If very large producers it is worth while to add special plant to deal with the tar distilled from cheap coal, by leading it back for combustion to the hottest part of the

furnace, or otherwise, and also to recover, as a saleable by-product, the small amount of ammonia usually present.

89. Calculations for Fuels.—When the chemical composition of a fuel is given, the following are the most important calculations which are usually required :—

(1) The quantity of air required for complete combustion.

(2) The calorific value of the gas.

The figures on p. 210, taken from Fowler's *Mechanical Engineers' Pocket Book*, as to the properties of the gases referred to atmospheric pressure and 32° F. are useful.

Ex. 1.—Suppose, for instance, we require to find the calorific value and the quantity of air required for complete combustion of Leeds gas. [See § 87.]

Take marsh gas = ·4178 cu. ft. per cu. ft. of Leeds gas.
Cu. ft. air required = ·4178 × 9·6 = 4·01. [Column *f*.]
Calorific value = ·4178 × 965·5 = 403·38. [Column *g*.]

Making similar calculations, which the student should check, for the other combustible gases, we shall get, on tabulating the results :—

	Calorific Value.	Cu. ft. of air required for complete combustion.
Marsh Gas	403·38	4·01
Olefines	65·88	0·59
Hydrogen	115·19	0·93
Carbon Monoxide . .	27·67	0·19
Totals . . .	612·12	5·72

Column *d* above is obtained from considering the chemical equation and the molecular weights.

Element.	Specific Heat.		Pounds in 1 cu. ft.	Pounds of Oxygen required per lb. for complete combustion.	B. Th. U. per lb.	Cu. ft. of air required per cu. ft. for complete combustion.	B. Th. U. per cu. ft.
	Constant Volume.	Constant Pressure.					
Hydrogen, H_2 . . .	2·406	3·409	·0056	8·0	52,750	2·4	294·8
Marsh Gas, CH_4 . .	0·467	0·593	·0447	4·0	21,600	9·6	965·5
Olefines	0·332	0·404	0·1174	3·428	20,260	21·6	2378·5
Carbon Monoxide, CO	0·173	0·245	·0783	0·571	4,340	2·4	336·7
Carbon Dioxide, CO_2 .	0·171	0·216	·1060				
Nitrogen, N_2 . . .	0·173	0·244	·0783				
Oxygen, O_2	0·155	0·217	·0891				
Carbon				2·67	14,500		
Air	0·168	0·237	·0808				
	a	*b*	*c*	*d*	*e*	*f*	*g*

4·35 lbs. of air contain 1 lb. of oxygen.

Thus for Hydrogen $\qquad 2H_2 + O_2 = 2H_2O$

$\therefore$ since molecular weight of H_2 is 2 and O_2 is 32

4 combines with 32 or 1 with 8.

For marsh gas. $\qquad CH_4 + 2O_2 = 2H_2O + CO_2$

Molecular weight of $CH_4 = 12 + 4 = 16$

$\therefore$ 16 combines with 64 or 1 with 4.

Finally take Carbon Monoxide

$$2CO + O_2 = 2CO_2$$

$\therefore$ 2 (12 + 16) combines with 32

i.e. 1 with $\frac{32}{56}$, or ·571.

Examples XV.

1. Explain the action of any gas producer with which you are acquainted.

2. Calculate the calorific value of acetylene gas (C_2H_4).

3. Distinguish between Mond and Dowson gas, giving approximately the calorific value of each.

4. Describe how the gas produced in blast furnaces has been used for the generation of power.

5. Compare the advantages of steam and internal combustion motor-cars when petrol is the fuel of both.

6. Describe briefly the chemical changes which occur in a suction gas producer.

7. The charge of an engine using lighting gas is 2 cubic feet of air and 0·17 cubic foot of gas. What volumes of producer gas and air must be used to generate the same amount of heat per cycle?

CHAPTER XVI.

TYPICAL INTERNAL COMBUSTION ENGINES.

90. The Otto Cycle.—Most internal combustion engines work on the system known as the *Otto Cycle*. It will be simplest to trace out one by one the processes involved in this before we consider the means by which they are effected.

It is really a compromise between attempts to obtain a machine of high thermal efficiency on the one hand and of mechanical simplicity on the other, some sacrifices having been made in both directions.

A cylinder is used, open at one end, and with a clearance space at the other end equal to one-fifth or more of the volume swept out by the piston. The crank-shaft has to be set in motion by hand, or by some suitable starting device.

Suppose that this has been done, and that the piston is just commencing an out-stroke. A combustible mixture of gas and air is drawn into the cylinder at atmospheric pressure. On the return stroke this charge is compressed into the clearance space, and the pressure rises from 15 lbs. to 90 or 100 lbs. per square inch absolute, since the compression is adiabatic. At about the dead point the mixture is ignited, and burns with great rapidity. As it cannot at once expand, the result of the combustion is a sudden rise of pressure to 300 or 400 lbs. per square inch. During the third stroke, therefore, the piston is driven forcibly forward, and the pressure falls gradually by expansion to 50 or 60 lbs. During the fourth and last stroke of the cycle, the products of combustion are expelled to make room for a fresh charge.

Fig. 125 is an indicator diagram taken from a 12 *H.P.* Crossley gas-engine; *MN* was drawn during admission or suction, *NR* during compression, *RS* represents combustion taking place, and *ST* the succeeding expansion. The exhaust valve opened at *T*, and on the fourth stroke the pencil traced the line *NM* once more.

The expansion and compression curves in an ideal engine working upon this cycle would be adiabatic curves, the equation to which is PV^{γ} = constant, where γ is the ratio of specific heats of the gas at constant pressure and constant volume respectively and is about 1·4.

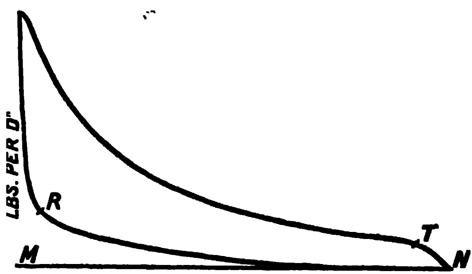


FIG. 125.—Indicator diagram from an Otto cycle gas-engine with a compression ratio of four to one.

The volume of the products of combustion, if reduced to atmospheric temperature and pressure, would be nearly the same as that of the original gas and air, so that changes of pressure are simply due to the production of heat.

The suction and exhaust portions, shown by the line *MN*, are not in reality straight lines, as shown in Fig. 125, but the spring of the indicator which is used is too strong to show the difference. To get a correct idea of the suction and exhaust we require a light spring diagram as shown in Fig. 126. This is obtained by putting a very light spring into the indicator and providing stops to save the spring from injury when the explosion occurs, the top horizontal line representing the spring pressed against the

stops. In the case shown it will be noted that there is a slight obstacle in the way of the exhaust gases causing a slight increase of pressure. The area of this portion of the diagram represents work done on the gas, and, if appreciable, must be subtracted from the other portion.

As there is only one working stroke in four, a large fly-wheel must be used as a reservoir of energy. Even then the speed is bound to be somewhat irregular.

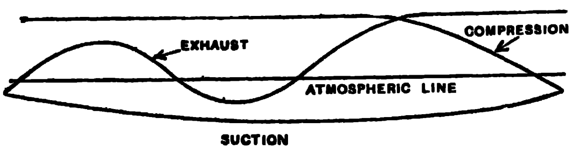


FIG. 126.—Light spring diagram for suction and exhaust lines in Otto gas-engine.

The exhaust gases are not fully expanded when they escape, and so carry away an unnecessarily large quantity of energy. If a simple means of extending the expansion could be applied it would lead to greater thermal efficiency. This would, however, mean a greatly increased stroke for a small increase in area of the indicator card, and there would thus be considerable increase in friction; so that although the thermal efficiency increased, the mechanical efficiency would decrease, and the net gain would be practically nil. The following practical example will show the advance that has been made on the steam-engine in spite of these shortcomings:—

Ex. 1.—Compare the thermal efficiency of a gas-engine using 20 cubic feet of lighting gas and a steam-engine using 2 lbs. of coal per brake horse-power per hour.

Heating value of coal per pound, 14,500 Th. U.
Heating value of gas per cubic foot, 650 Th. U.
Heat used in doing one horse-power hour of work with gas-engine

$$= 650 \times 20 = 13,000 \text{ Th. U.}$$

Heat used in doing one horse-power hour of work with steam-engine

$$= 14,500 \times 2 = 29,000 \text{ Th. U.}$$

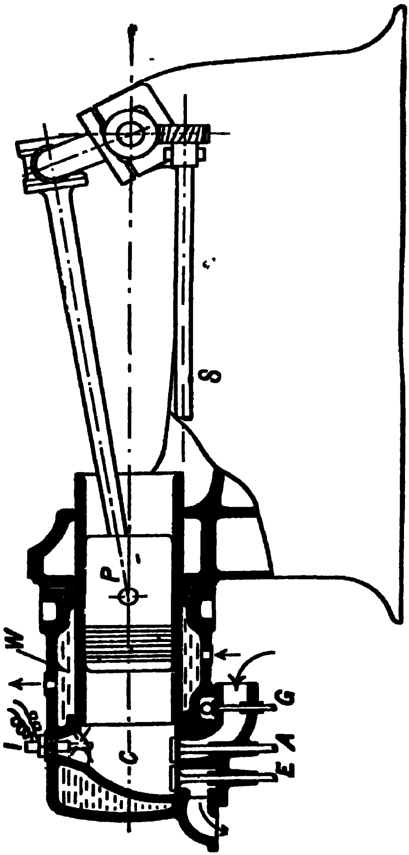


FIG. 127.—Section of a small gas-engine.

P = Piston.
C = Clearance space.
G = Gas valve.
A = Air valve.
E = Exhaust valve.
S = Counter-shaft.
I = Ignition plug.
W = Water jacket.

This is of course a comparison of thermal efficiencies. To get a comparison of commercial efficiencies we must allow for the price of the coal and the gas, which will vary with the locality.

91. Description of a Gas-Engine.—Fig. 127 is a sectional view of a small gas-engine. It will serve to illustrate the essential features of all engines of this type. *P* is a hollow piston to which the connecting-rod is directly coupled, *C* is the clearance space at the back of the cylinder, *A* is the air valve opening into the cylinder, and *G* the gas valve opening

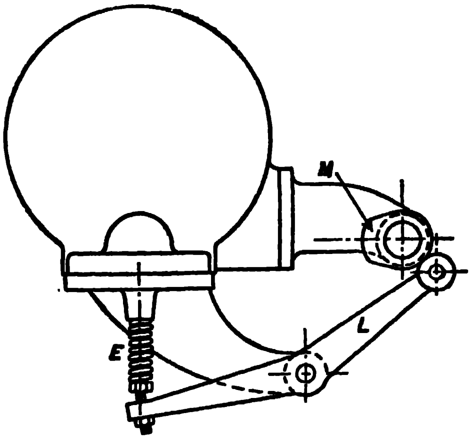


FIG. 127A.—Mechanism for raising valves in a gas-engine.

into the air supply pipe. These two are so proportioned that when they are both raised the correct mixture (1 cu. ft. of lighting gas to 11 cu. ft. air) will be admitted. *E* is the exhaust valve, the mechanism of which is shown in Fig. 127A. It is lifted by a lever, *L*, actuated from a cam, *M*, on a countershaft, *S* (see also Fig. 127), driven, by gearing, at half the speed of the crank-shaft, and is brought back by a stout spring. The other valves are worked in

the same way. The charge is ignited by an electric spark allowed to pass automatically at the right moment between the metal points on the plug *I*. Another method of ignition is to connect a porcelain or iron tube of small bore with the clearance space. The outer end of this tube is kept red-hot by an external flame. It remains full of the products of combustion except towards the end of the compression stroke, when a portion of the live charge is compressed into it. Its length is so adjusted that the latter just reaches a part hot enough to ignite it at the dead point.

The student should supplement the description by making an inspection of the mechanism itself, because most students can learn more readily from actual inspection of a mechanism than by reading a description of it. Internal combustion motors are now so common that he should have no difficulty in obtaining access to one.

Details of the various parts of gas-engines are given in the next chapter.

The temperature of combustion is so great that the cylinder would soon get red-hot if it was not kept cool by a surrounding jacket, *W*, through which water circulates. There must also be a circulation of water through the piston when this exceeds 17 or 18 inches in diameter, and in very large engines even the valves are water-cooled.

92. Oil-Engines.—As mentioned in the previous chapter, heated vaporisers have to be employed when non-volatile oils such as paraffin are used as fuels. In the Hornsby oil-engine, for example, there is fitted to the back of the cylinder an unjacketed cast-iron dome (see Fig. 128), with protruding ribs on the inside, to increase its radiating surface. It is heated red-hot with the blow-lamp shown before starting. A small quantity of oil is pumped into this vaporiser during each cycle and is at once evaporated; air is admitted to the cylinder, as in a gas-engine, and is compressed into the vaporiser during compression. Thus an explosive mixture is formed which is ignited, when the dead point is reached, by the heat of the chamber, and that due to the work done upon itself. The ratio of compression

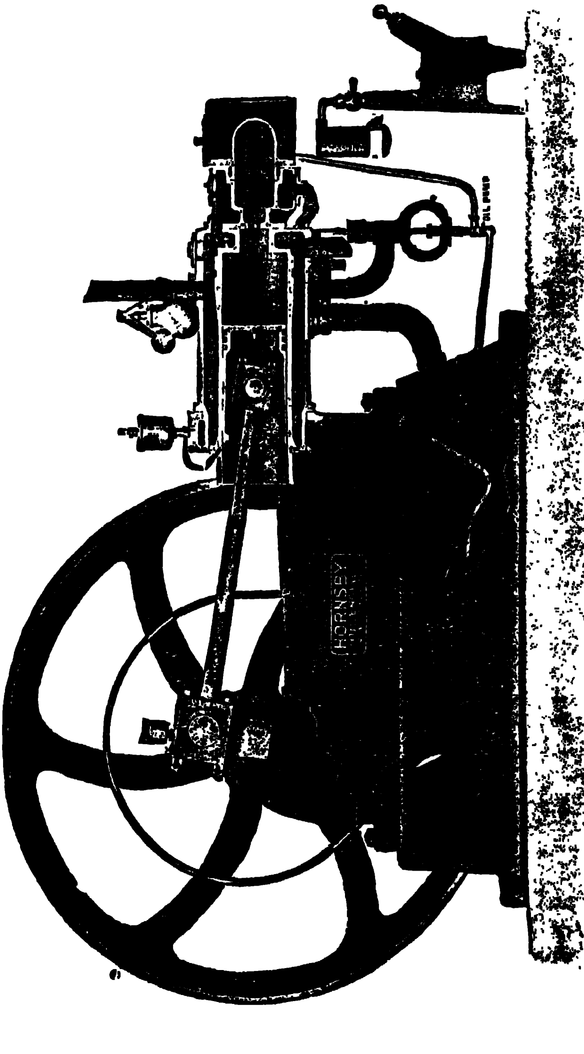


FIG. 123.—Section of Hornsby oil-engine.

has to be very carefully adjusted to ensure this. Provision is made, by means of plugs of different sizes, for varying the volume of the clearance space to suit the temperature of ignition of the oil used.

When once started the heat of combustion keeps the vaporiser at a sufficiently high temperature and no lamp is necessary.

The governor regulates the supply of oil by opening a bye-pass from the pump back to the storage tank, so that only a small portion of the oil pumped by the pump enters the reservoir if the speed is above the normal, the remainder returning to the tank.

In some other oil-engines the oil is vaporised, as required, in a separate vessel, heated by the exhaust gases, and the vapour is drawn from this through a valve into the cylinder.

93. The Diesel Oil-Engine.—The Diesel oil-engine uses heavy unrefined petroleum, and is one of the most efficient engines that have been devised, the thermal efficiency reckoned on the Brake Horse Power coming as high as 35 per cent., with a fuel consumption of ·41 lb. per B.H.P.

It differs from the ordinary gas-engine in that there is no explosion; pure air only is drawn into the cylinder, and this is compressed to a temperature higher than that required to ignite the oil, which is injected as a fine spray into the highly compressed air and burns gradually as long as the injection is maintained. During this whole period the pressure does not rise above the compression pressure.

The engines may run on a four-stroke or a two-stroke cycle, the former being as follows:—

1st stroke.—Air is drawn into the cylinder.

2nd stroke.—The air is compressed by the backward action of the piston to a pressure of about 450 lbs. per sq. in.

3rd stroke.—Injection of the petroleum which immediately ignites by the heat of the compressed air, whose temperature is about 1000° F.

4th stroke.—Expulsion of the products of combustion.

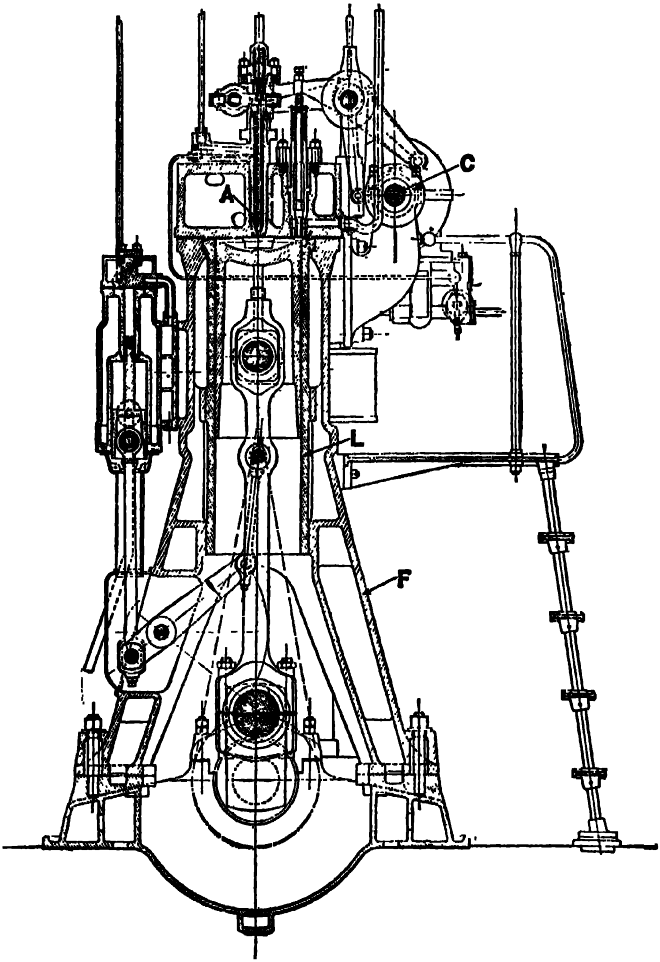


FIG. 129.—Section of Diesel engine.

The four-stroke engines are of the vertical type shown in Fig. 129, and have a strong cast-iron A-frame *F*, the upper part of which forms the outer cylinder of the water-jacket; into this upper part is fitted a liner *L* of special close-grained cast iron, which is water-jacketed for almost its entire length.

The four valves are arranged in the cylinder cover: the central valve *A* is a needle valve which admits fuel to the cylinder immediately before the end of the compression stroke; the other valves are air-inlet, exhaust, compressed-air, and starting valves respectively. All the valves are spring-closed and are operated by levers on a cam-shaft *C* driven at the same speed from the crank shaft by toothed gearing.

The fuel-pump of the engine operates as follows:—

The plunger draws a full stroke of oil from a reservoir into the pump chamber past the inlet valve; this quantity of oil is in excess of that required for combustion. The

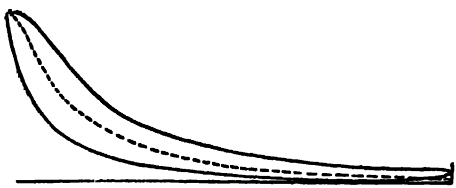


FIG. 130.—Indicator cards for Diesel engine.

excess is returned past the suction valve on the delivery stroke by the action of the governor, which holds open the inlet valve for a sufficient length of time to allow the excess fuel drawn in to escape into the suction pipe, so that the amount of fuel pumped in is controlled by the governor at every stroke.

Fig. 130 shows two indicator cards obtained in an actual test and kindly supplied by the Diesel Engine Co., Ltd.; the full curve is for full load and the dotted curve is for half load.

Although the engine is specially suitable for crude petroleum, any oil of calorific value not less than 18,000 B.Th.U. per lb. can be used.

The mechanical efficiency of the engine is about 73 per cent. The speed of the Diesel engine, especially the two-stroke type, can be controlled within wide limits, and is thus very suitable for marine propulsion.

94. Indicated Horse-power and Efficiency of Gas and Oil Engines.—The calculation of the indicated horse-power of an Otto cycle-engine requires a little thought.

The work done during the first and last stroke of the piston may, in most cases, be neglected; the mean pressure during the compression stroke is given by the mean height of the curve NR, Fig. 125—call this p_1; the mean pressure during the working stroke is given by the mean height of the curve STN—call this p_2. When, owing to the action of the governor, no explosion occurs after compression, the indicator pencil will follow the line RN, and the mean forward pressure will be p_1.

Let A = area of piston in square inches.
L = stroke of piston in feet,
E = no. of explosions per minute.
C = no. of compressions without explosion per minute.

Positive work done per minute

$$= p_2 A L E + p_1 A L C \quad \text{ft. lbs.}$$

Negative work done per minute

$$= p_1 A L E + p_1 A L C \quad \text{ft. lbs.}$$

$\therefore$ Nett work done per minute

$$= (p_2 - p_1) A L E \quad \text{ft. lbs.}$$

$$\therefore \text{I.H.P.} = \frac{(p_2 - p_1) A L E}{33{,}000}$$

$$= \frac{p A L E}{33{,}000}$$

where $p = p_2 - p_1$.

p may be obtained directly from the mean height of the diagram *NRST*, and is usually done so in tests of engines. The area of the indicator card is measured by a planimeter, and this area is the work done per explosion or $p \times L$. Some planimeters are, however, set so as to give the mean pressure and not the area of the diagram; in this case the reading of the planimeter is what is taken for p in the formula.

Fig. 131 has been drawn to give some idea of how the energy supplied to a modern internal combustion engine is disposed of. It shows what a large amount of heat is carried away by the cooling water. Any attempt to reduce this quantity without increasing the ratio of expansion does not, as might at first be expected, improve the efficiency; it merely increases the temperature of the waste gases.

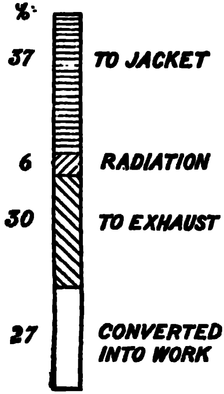


FIG. 131. — Distribution of the energy of each cubic foot of gas supplied to an efficient gas-engine.

It must be remembered that 15 or 16 per cent. of the work done on the piston is used up by the machine itself, as against 10 or 12 per cent. in the steam-engine, so that the part of the area shown as "converted into work" can be regarded as made up of the useful work and that wasted on the engine itself.

The higher the ratio of compression in an engine using the Otto cycle, the better will be its efficiency. The practical limit of adiabatic compression is the condition that the maximum temperature produced must not exceed that at which combustion commences. This temperature is much lower for paraffin than for lighting or producer gas.

If a vertical line be drawn across the diagram given in Fig. 125, say one-sixth of its length from *M*, the part to the right of this will show approximately the much smaller proportion of work obtainable from an engine using five-sixths the quantity of gas, but compressing it to three-eighths in place of one quarter of its original volume.

95. Testing Gas and Oil Engines.—In making a thorough test of a gas-engine, the following observations have to be made:—

Indicated Horse Power.—This is obtained as explained in the previous paragraph.

Brake Horse Power.—This can be measured either by means of a dynamometer, or else by driving a dynamo and measuring the electrical output and allowing for the efficiency of the dynamo. The simplest dynamometer, and the most common for small powers, is the rope brake. A rope or ropes, held together by wooden blocks, is or are passed round the flywheel of the engine, and a weight is suspended at one end and a spring balance at the other. The number N of revolutions per minute of the engine are counted, and the diameter D in feet of the flywheel to the centre of the rope is measured; then if W is the difference in pounds between the weight at one end of the rope and the reading of the spring balance at the other, we shall have Brake Horse Power

$$= \text{B.H.P.} = \frac{\pi N D W}{33{,}000}.$$

Jacket Measurements.—The jacket water is measured by graduated tanks carrying floats by which the level of water can be accurately obtained, and the outlet and inlet temperatures are also taken; then the heat given up to the jacket in B.Th.U. per minute is equal to the product of the mass of water passing per second in pounds by the rise of temperature in $°F$.

Gas Measurements.—The consumption of gas must be measured by a gas-meter, and the temperature and pressure in the meter and the height of the barometer must also be read, so that the consumption can be standardised as explained in § 87.

If the gas is not one of known composition, an analysis must also be made, and the calorific value should be determined experimentally by means, for instance, of Junker's calorimeter, which is described on p. 153.

Exhaust Measurements.—These are not often made, on account of their difficulty and unreliability. The exhaust

temperature is sometimes measured by special thermometers, but is more usually calculated from the indicator card. The exhaust gases can be analysed, or their composition can be calculated from the composition of the mixture.

96. Motor-Car Engines.—The Otto cycle is used in nearly all petrol-driven motor-car and launch engines. Two, four, or six cylinders are employed, and large powers are obtained by working at a high speed.

With four cylinders an impulse can be obtained twice in every revolution, and, if the two outer cranks point in the same direction and the two inner cranks are opposite to them, the reciprocating parts will be balanced, and the engine will thus run much more smoothly.

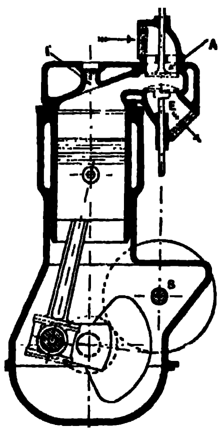


FIG. 132.—Cross-section of a motor-car engine.

Fig. 132 shows a section through one cylinder of a motor-car engine. The explosive mixture of petrol and air is admitted through the valve *A* during the suction stroke. After compression, this charge is ignited by an electric spark from a sparking plug inserted at *I*, and when it has done its work in driving the piston it is allowed to escape through the exhaust valve *E*. The inlet and exhaust valves are actuated by cams on the half-speed shaft *S*.

The cylinder walls and head, including the space round the ports, are water-jacketed. Circulation is maintained by a pump, the hot water discharged being cooled by passing it through a radiator placed at the front of the car and exposed to the full force of the wind.

The speed of a motor-car engine may be controlled by throttling the air supply during admission, and thus reducing the amount of the charge taken in, or by retarding the ignition so that combustion only commences after a portion of the working stroke has been performed.

In engines of large power governors are provided, and in the most modern engines are usually of the variable admission type; most small-powered engines are controlled by hand.

The speed of petrol-engines cannot be reduced much without robbing them of their power, so that a motor-car engine cannot be run slower for going up-hill; this necessitates the use of change-speed gearing, by means of which the car can run more slowly without slowing down the engine; the change-speed gearing is usually of the sliding-pinion type, and provides for three speeds forward and one reverse.

Silencers are provided to deaden the noise of the exhaust; this is done by splitting the steam up into fine jets by providing baffle pins and fine holes at the ends of the exhaust pipes; care must, however, be taken to provide sufficient area for the exhaust in order to avoid undue back pressure.

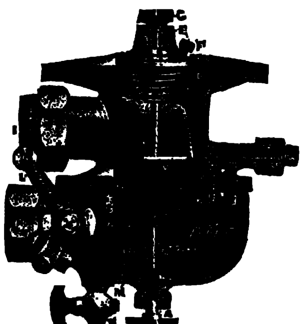


FIG. 133.—Section of a Kingston carburettor.

A most important member of every petrol-motor is the carburettor. Its purpose is to inject a proper quantity of petrol into the air drawn in during the suction stroke in such a way that it will be immediately vaporised.

A simple carburettor containing the most essential features is illustrated in Fig. 133. The union *H* is connected directly with the inlet pipe of the engine, so that all the air taken in must enter at *I*, and pass through the passage indicated by arrows. Surrounding the passage is an annular chamber in which petrol is maintained at a constant level by means of a cork float actuating the valve *B* in a supply pipe leading from the storage tank. The only outlet from the float chamber is through the adjustable needle-valve *T*, above the surface of the liquid.

During each suction stroke of the engine there is a slight reduction of pressure in the air passage sufficient to draw a spray of petrol through the valve *T*. The quantity of petrol thus mixed with each charge of air depends upon the reduction of pressure in the carburettor; the latter is regulated by the automatic valve *V*, which is controlled by a spring, *S*, and diaphragm, *D*. When the suction becomes excessive the diaphragm is depressed by the atmospheric pressure above it, and the valve *V* opens more freely.

A throttle-valve, *L*, is introduced in such a position that it may be used to throttle the supply to the cylinder without increasing the suction in the carburettor. A correct mixture is thus obtained at all powers and all speeds.

96a. Two-stroke Engines.—As explained in § 90, the Otto Cycle is used for nearly all internal combustion engines, and for each explosion there are four piston strokes; but successful attempts have been made in recent years to build an engine where there is an explosion for each *two* piston strokes, *i.e.* for each revolution of the crank shaft. Such an engine is known as a *Two-stroke Engine*. The four operations corresponding to the four strokes of the Otto Cycle must still take place. There must be admission of gas, compression of charge, expulsion of charge and exhaust. In the Otto Cycle the admission of charge is effected by the drawing-in action of the piston, and the exhaust by the expulsive action of the piston; but, in the two-stroke engine the introduction of charge is effected by pressure from outside the cylinder, and this charge when introduced blows the burnt-out gases out through the exhaust. The two strokes for intake and exhaust are thus saved. Fig. 133*a* shows a diagram of a simple form of Two-stroke Engine.

A is the cylinder. *B* the piston. *C* crank-case. *D* transfer port, the object of which will be explained shortly. *E* exhaust. *F* baffle for deflecting the charge. *I* the inlet pipe communicating with the carburettor.

In this type of two-stroke engine the pressure necessary to drive the charge into the cylinder is provided by the movement of the piston into the crank-case. The crank-

case is a sealed chamber. It will be noticed that the inlet pipe communicates with the crank chamber and not with the cylinder. Now let us consider what would happen with this two-stroke engine if the exhaust were open to the air and the crank-shaft were rotated by some outside agency. If there were a valve in the intake pipe, as there is when the engine is working, the arrangement would act as a not very efficient air pump. Consider the piston *B* at the top of the stroke as shown: the direction of rotation is immaterial. The ports *E* and *D* are closed, and there is no outlet from *C*. As the piston descends, a partial vacuum is produced in *A*, and the air in *C* is compressed until the piston has descended so far that *E* is opened. Air now enters from *E*; but in *A* we shall reach only atmospheric pressure, and there is something over atmospheric pressure in *C*; and when the further descent of the piston opens port *D* into the cylinder, air will pass from *C* through the transfer port into *A*, and a corresponding amount of air will be forced out through *E*. The piston now rises, closing *D*, and in its further movement compresses the air in *A* and draws fresh air through the inlet into *C* until the top of the stroke is reached.

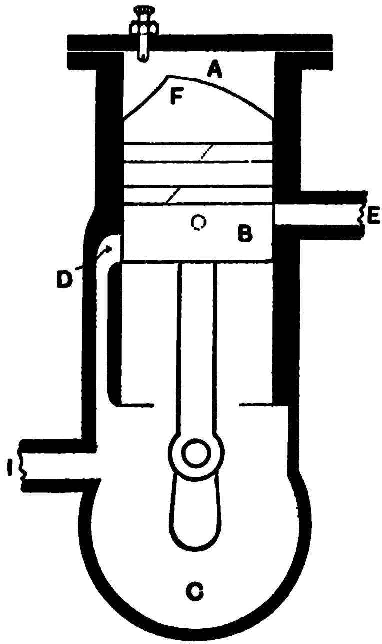


FIG. 133a.

The same series of operations will take place with each

revolution, but after the first, there will be no rush of air in through E, as there is compressed air in the top of the cylinder at the beginning of the stroke, and this compressed air expands to atmospheric pressure on the downward stroke. With each upward stroke we shall thus get an intake of air to C, and at the end of each downward stroke a rush of air from C through D into the cylinder, and the expulsion of air through E at the same time.

Now let us consider the action when an explosive charge is admitted through the intake instead of air, and a spark passes through the plug when the piston is at or near its highest point. In this case, what the piston compresses in its upward motion is the explosive charge, and, on the passage of the spark, the usual impulse is obtained, forcing the piston downwards. In its downward motion the piston is compressing a new charge in the crank chamber and, at the lowest point, this new charge rushes up through the transfer port and drives the burnt gases out of the exhaust. The baffle or deflector F is intended to send the gases brought in through the transfer port to the top of the cylinder so that only burnt products pass out through E. It is quite obvious that in so far as unburnt fuel passes out through E there will be a drop in the power and efficiency of the engine; and the positions of the ports, the design of the baffle and the ratio, cylinder volume to crank-case volume, are extremely important in a two-stroke engine.

It will be noted that the two-stroke engine needs no counter-shaft and is very simple in its valve arrangements. It is frequently lubricated by using a mixture of petrol and lubricating oil instead of pure petrol, and this mixture, entering the crank case first, is able to keep the bearings as well as the cylinder in good running condition. The engine lacks flexibility, *i.e.* it rapidly loses power and efficiency if run at a speed varying much from its standard speed; but it has been found a suitable engine for small power units such as motor cycles.

EXAMPLES XVI.

1. Compare the working cost of the engines quoted in Example 1 (p. 214), when coal is fourteen shillings a ton, and gas two shillings and sixpence per 1,000 cubic feet.

2. Describe the Otto cycle.

3. Copy Fig. 125 to a large scale on squared paper, and draw curves to the equation

$$p\,v = \text{a constant}$$

through point N and a point near S, taking the atmospheric pressure at 15 lbs. per square inch.

Why do these curves not correspond with those in the diagram?

4. Why should the relative thermal efficiency of gas and steam engines be calculated on the brake and not the indicated horse-power?

5. Sketch in section a gas-engine cylinder, showing the valves and piston. (S. and A. 1900.)

6. Sketch a gas-engine indicator diagram. How is it used in finding the indicated horse-power? State clearly what information is necessary. Why must we know the number of explosions per minute rather than the number of revolutions? (S. and A. 1900.)

7. In the engine from which the indicator diagram, Fig. 125, was taken, 105 explosions were occurring per minute; at what horse-power was it working? Piston diameter 7", stroke 14".

8. Draw up a heat balance-sheet from the results of the following oil-engine trial:—

Diameter of cylinder, 10".
Stroke, 20".
Mean effective pressure, 75 lbs. per square inch.
Explosions per minute, 66.
Weight of oil used per hour, 16·2 lbs.
Heat equivalent of oil per lb., 19,000 Th. U.
Cooling water used per minute, 34·71 lbs.
Initial temperature of water, 58° F.
Final temperature, 106° F.

9. In a gas-engine cylinder where $v = 2{\cdot}2$ and $p = 14{\cdot}72$ it was known that the temperature was 130° C. What is the temperature when $p = 122$ and $v = {\cdot}4$?

10. A gas-engine has a piston of $4\frac{1}{2}$" diameter, 9" stroke; the governor is set for 150 revolutions per minute; what mean effective pressure is assumed if the engine is rated at 2 h.p.?

CHAPTER XVII.

DETAILS OF INTERNAL COMBUSTION ENGINES.

97. Valves.—The valves are usually of the mushroom type with long spindles to give good bearing. Fig. 134 shows the valves in the Tangye's "T type" gas-engine, reproduced by permission. The combustion chamber is a separate casting fitted at the end of the cylinder, and the admission valve *G* is fitted by a cotter *I* to a spring cap *H*, and set screws *F* can be inserted into the spring *A* to facilitate removal of the valve, the engine being first turned so that the valve is slightly opened; in a modified construction a plate *J* is pressed down by nuts or studs *K* to take the pressure off the spring for removal. A spring *L* is provided to enable the gas valve to close on its seat a little while before the admission valve *G* closes. The exhaust valve *M* is connected by a peg *R* to a nut *Q* which bears against a spring cap-plate *P*, which can be lifted to facilitate removal of the valve by nuts or studs *O*.

Fig. 135 shows the arrangement in the Premier Single Cylinder gas-engine, the scavenging action of which is described in connection with Fig. 143, which should be looked at in conjunction with Fig. 135. The gas passes by a cock *O* to the space *M* to the annular gas valve *G*, where it mixes with the air entering by the parts *PP*. The gas-valve *G* and admission valve *E* are operated by rods *K*, *L*, respectively operated from the cam-shaft *V*, from which the exhaust valve *H* is also operated, as is clearly shown. It will be noted that the combustion chamber and exhaust port are water-jacketed.

98. Ignition Devices.—As indicated in § 91, the ignition is effected either by a tube heated by a Bunsen burner or else by means of an electric spark. The electric ignition is

obtained usually by (*a*) a high-tension spark obtained by the aid of an induction coil and an accumulator, a spark being made at the requisite time by means of a contact

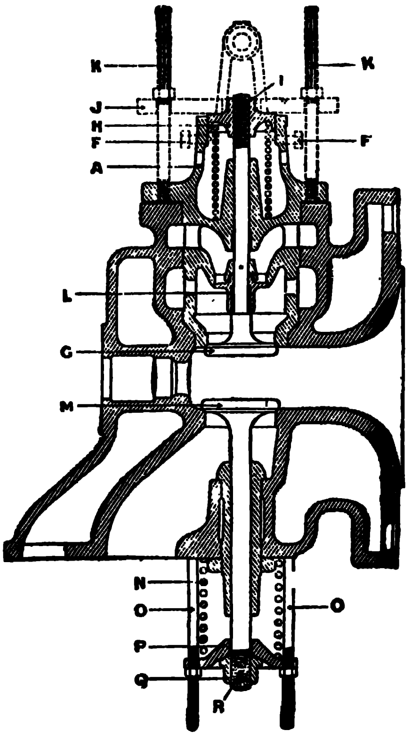


FIG. 134.—Valves of Tangye gas-engine.

mounted on the cam-shaft; or (*b*) a low-tension spark obtained by a magneto mechanism mounted on the engine; this has the great advantage that no charging of accumulators is required.

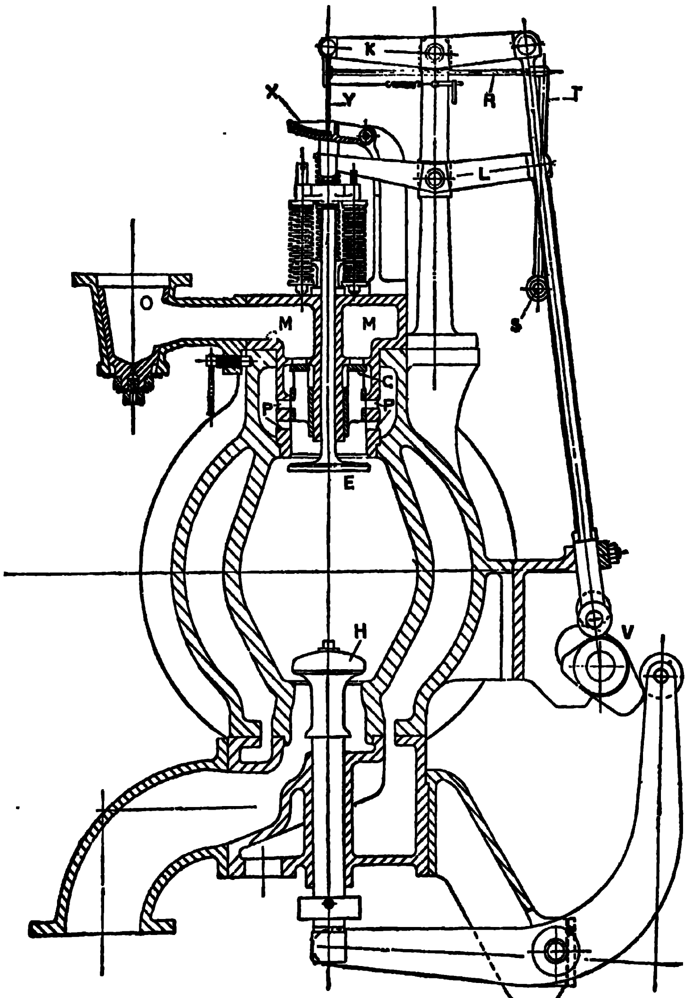


FIG. 135.—Valves in Premier gas-engine.

Fig. 136 shows the patent magneto mechanism used on the Tangye gas-engine, reproduced by permission. A crank *A* is mounted on the cam-shaft *B*, and is connected to a hooked connecting rod *C* which engages a lever *D* fixed upon the spindle of the armature of the magneto machine. As the crank *A* revolves, it causes the hook end of the connecting rod *C* to engage with the lever *D* for a certain dis-

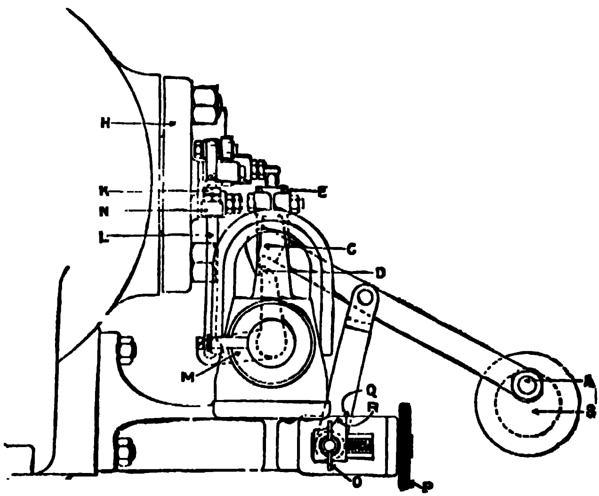


FIG. 136.—Tangye magneto gear.

tance and to release it at the correct time; the armature is then rapidly moved back to its original position by means of the laminated springs *E*. The current passes from the machine to the sparking plug *H*, and the sparking points are separated to cause the spark by regulating nuts *K* on the end of a rod *L* attached to the lever *M* striking the lever *N*. The time of ignition is varied by causing the connecting rod to release sooner or later by slacking a fly-nut *O* and turning a hand-wheel *P*. A pointer *R* shows the ignition time on a scale *Q*.

99. Connecting Rod and Piston.—Fig. 137 shows the connecting rod and piston used on the Premier gas-engine. The piston is hollow and carries spring rings *R*,

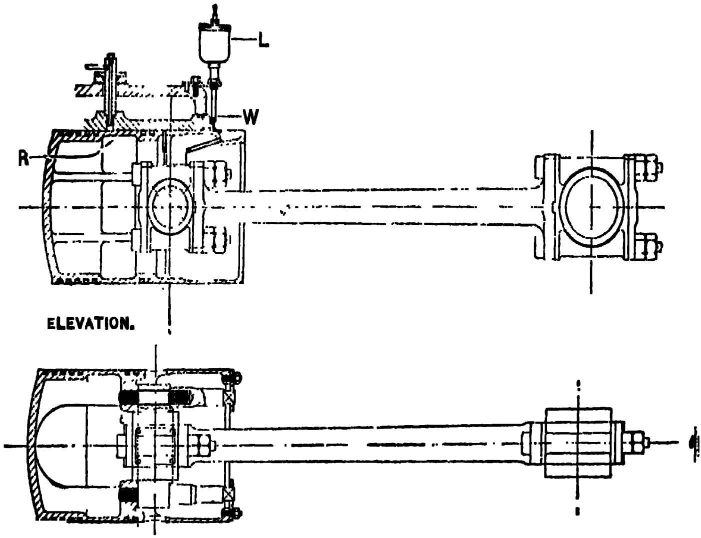


FIG. 137.—Piston and connecting rod.

and a lubricator *L* on the cylinder carries a wick *W* which lubricates the piston. The connecting rod has marine type gun-metal bearings at each end and abnormally long hardened bolts are employed.

100. Lubricating Means.—*Main Bearings.*—Fig. 138 shows the ring lubrication of the main bearings which is used on the Crossley gas-engines. The ring *R* passes through a slot in the centre of the upper bearing and rests on the shaft, its end dipping into the oil-well, the depth of oil in which can be seen by the gauge-glass at

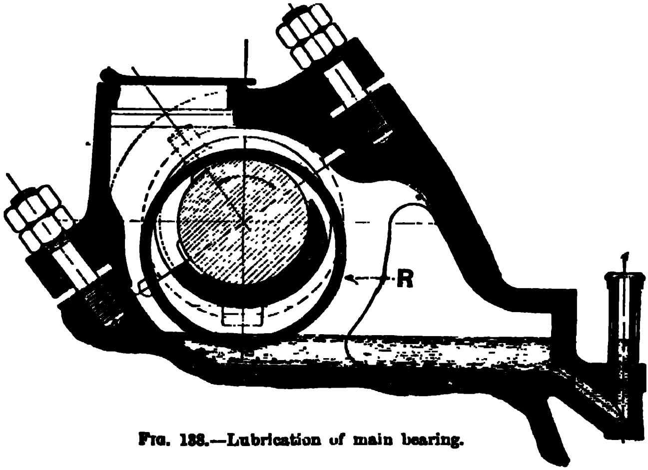


FIG. 188.—Lubrication of main bearing.

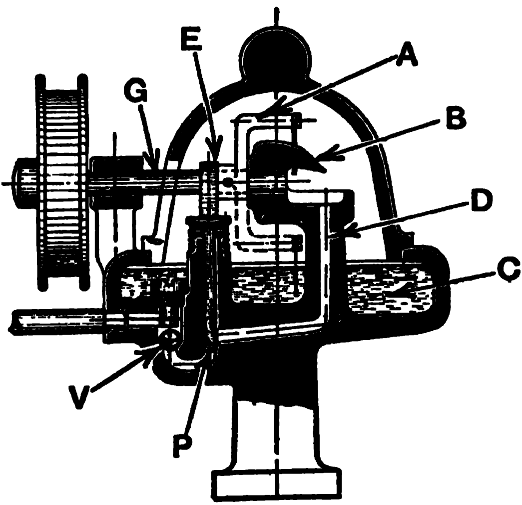


FIG. 189.—Forced lubrication for cylinder.

the side. As soon as the main shaft revolves, the ring *R* moves round it and delivers oil to the centre of the bearing, surplus oil returning to the well.

Cylinder Lubrication.—One method of cylinder lubrication was shown in Fig. 137. An interesting method of forced lubrication used on the Crossley engines is shown in

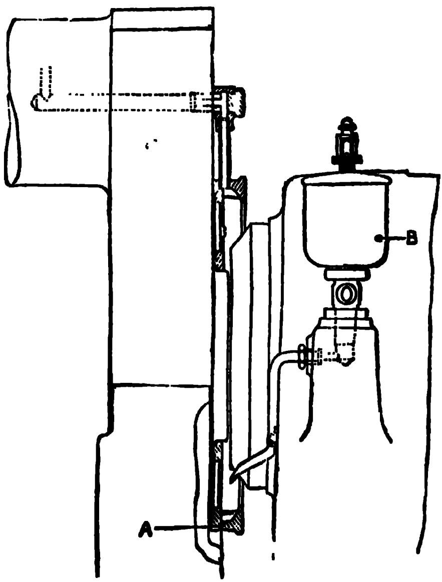


FIG. 140.—Crank-pin lubrication.

Fig. 139. A pulley-driven shaft *G* carries a crank *A* carrying a loosely mounted wire that dips into the oil-well *C* as the shaft rotates. The wire comes against a beak *B* to which it delivers the oil, which then drops down a pipe *D* to a pump-plunger *P*. This plunger is driven by a cam *E* and forces the oil through a ball-valve *V* to the cylinder. The forced system of lubrication enables the oil to be deli-

vered near the back of the piston and ensures that the piston rings are amply lubricated.

Crank-pin Lubrication.—Fig. 140 shows the method for lubricating the crank-pin adopted in the Tangye gas-engine. Oil passes from a sight feed lubricator *B* to a ring *A* connected to the crank. The action of centrifugal force causes the oil to travel to the other side of the ring and to find its way to the crank-pin as shown in the figure. The ring *A* is fitted with a perforated guard which prevents cotton waste, etc., from getting into the oil hole in the crank-pin.

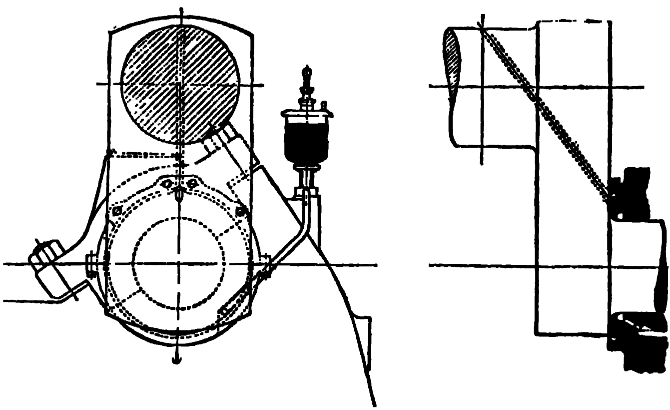


FIG. 140A

Fig. 140A shows the method of lubricating the crank-pin adopted in the Crossley engines. Oil flows from a sight-feed lubricator to a groove in the bearings surrounding the main shaft, and centrifugal force distributes the oil by the passage shown in dotted lines to the crank-pin.

101. Starting.—Engines of small power are usually started by hand. The flywheel is pulled round so as to suck a charge of gas and air into the cylinder, and this

charge then becomes compressed and exploded. To avoid high compression when starting, a special starting cam is usually provided alongside the ordinary cam for operating the exhaust lever. Fig. 141 shows the arrangement in the Tangye gas-engine, *A* being the relief or starting cam; for starting, the roller *B* on the exhaust valve lever is moved to the position shown dotted. As soon as the engine is running, the roller is moved to engage the large cam and is fixed in position by a pin *C*.

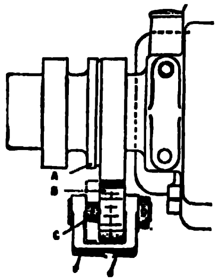


FIG. 141.

For larger powers, self-starters have to be used. In the Manchester self-starter gas is admitted into the cylinder, and the gas and air pass out through a cock and a contracted outlet, and the mixture is ignited by a naked flame. As the mixture gets richer the colour of the flame changes, and finally the gas supply valve is closed and the flame strikes back and explodes the mixture in the cylinder, thus starting the engine. In another type a mixture of air and gas are pumped into the cylinder and exploded, the flywheel having been levered round so that the connecting rod is approximately at right angles to the crank.

Compressed-air starters are also largely used, and seem likely to supersede the other types. In an arrangement patented by Messrs. Fielding and Platt, when the engine is about to be stopped after a run, the gas is turned off, and the piston and engine cylinder, by a slight alteration in valves, is converted into an air-compressor, which discharges into a reservoir until a pressure of about 60 lbs. per sq. in. is obtained, so that the energy stored in the flywheels is utilised. Compressed air at higher pressure than this is often utilised for starting.

103. Governing.—The means for maintaining a uniform speed in gas-engines may be classified as follows:—

(*a*) "*Hit-and-miss Type.*"—In this type, which is used

principally for small powers, the governor is connected to the lever for operating the gas, or to the lever for causing the explosion, so that if the speed is beyond the normal no explosion takes place. The governors are either of the centrifugal or inertia types. Fig. 142 shows diagrammati-

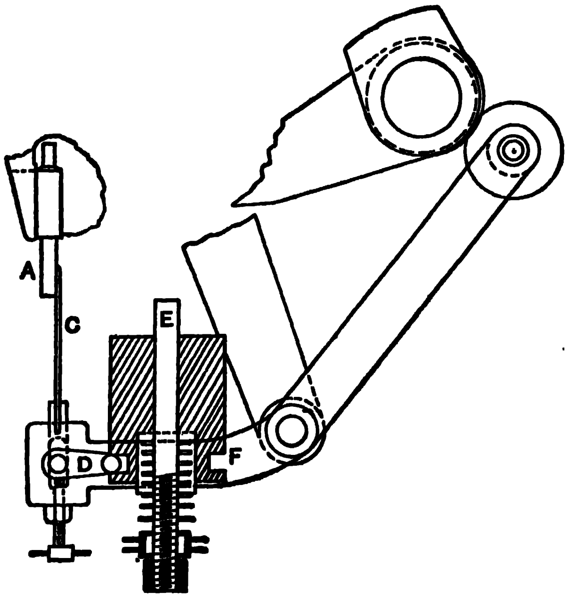


FIG. 142.—"Hit-and-miss" governor.

cally the arrangement of inertia governor used on the smaller Hornsby-Stockport engines. The gas-valve spindle *A* has a notch which is adapted to be engaged by a blade *C* connected to a cam-operated lever. Fixed to the lever there is a spindle *E* carrying a spring-pressed weight *F* which engages a bell-crank lever *D* which carries the

blade *C*. The tension in the spring is adjustable, and if the speed increases above the normal amount, the movement of the lever also increases, and the inertia of the weight causes the bell-crank lever to rotate slightly in a clockwise direction, and the blade *C* thus misses the notch in the valve-spindle *A*.

(*b*) *Variable-admission Type.*—In this type the governor causes the amount of explosive mixture to be varied so that there is an explosion at every stroke and the variation in speed is thus less, although the gas consumption may be slightly greater; it is similar to governing a steam-engine by varying the cut-off. The governors are of the usual ball-type, and act upon the cam mechanism for controlling the admission so that the amount of opening of the admission valve is varied.

(*c*) *Variable-mixture Type.*—In this type the quality of the explosive mixture is varied by varying the amount of opening of the gas valve. Fig. 135 (p. 231) shows this type as used in the Premier gas-engine. The annular gas valve *G* is operated from a lever *K* by a pivoted blade *Y* which engages a pivoted arm *X* connected to the valve. The governor oscillates a spindle *S*, which is connected by arms *T*, *R* to the blade *Y*, and when the governor rises the blade *Y* is thrown to the left, thus reducing the opening of the gas valve, whereas when the governor falls the blade moves to the right and increases the opening.

(*d*) *Exhaust Type.*—In this type the governor acts upon the exhaust valve and keeps it open when the speed becomes too great. As no vacuum will then be formed during the return stroke, no fresh charge is sucked in, and so no further explosion takes place until the speed has returned to the normal.

103. Scavenging.—This operation consists in clearing the cylinder and clearance spaces from the products of combustion which otherwise mix with the incoming charge and tend to weaken it. Early engines were sometimes provided with two additional idle strokes to ensure this scavenging action, but it was found that the increased

economy was not sufficient to make up for the loss of two strokes.

In the Atkinson and Crossley method of scavenging a very long exhaust pipe—about 65 feet long—is used. The momentum of this long column of gas causes the air, which is admitted just before the end of the exhaust stroke, to sweep through the combustion chamber and drive out the products of combustion.

Fig. 143 shows the action of the Premier positive scavenging engine. The piston is a differential one, the portion *A* acting as an air-compressor, the clearance spaces of which are so large that the pressure does not rise above 5 lbs. per sq. in. Air enters from a pipe *SB* through valves *F*, and part enters the cylinder *N* through a port *D*, and the remainder enters the passage *C* and passes through the valve *P* to the combustion chamber *Z*. During the exhaust stroke the piston *A* compresses the air behind it until the piston reaches the point shown in the figure. The admission valve *E* is then opened and allows the compressed air to sweep through the combustion chamber in the manner indicated by the arrows.

Examples XVII.

1. What do you understand by "scavenging" as applied to a gas-engine? Describe one method of effecting this.

2. Explain one mechanical method of starting a gas-engine.

3. Describe with the aid of sketches one method of governing a gas-engine on the "hit-and-miss" principle.

4. Describe the method of governing oil and gas engines by varying the charge.

5. Discuss the relative advantage of "hit-and-miss" and the variable-mixture method of governing oil and gas engines.

6. Describe with the aid of sketches one method of electrically igniting the charge in a gas or oil engine.

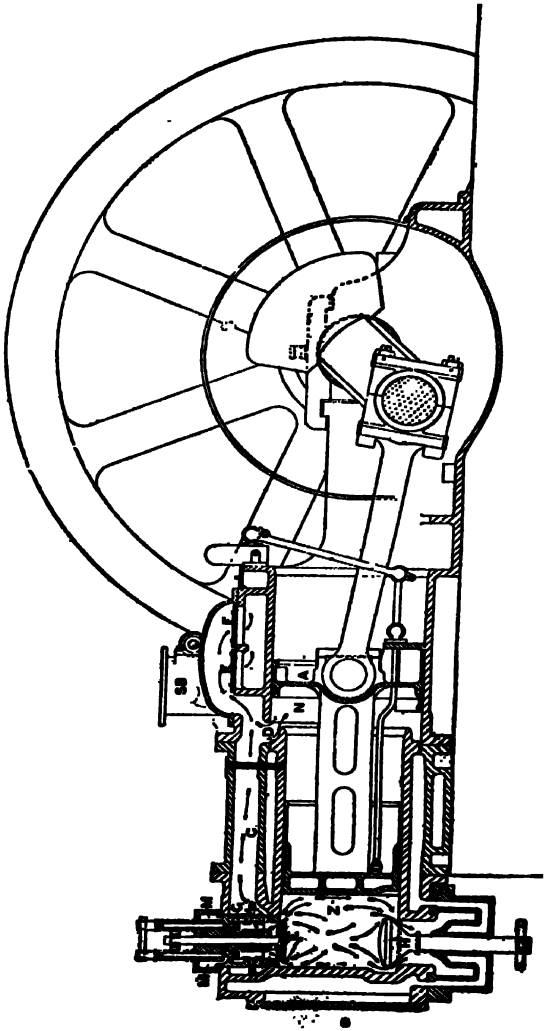


FIG. 143.—Section of Premier Positive scavenger type gas-engine.

7. Describe the action of the valves in a gas-engine.

8. Sketch roughly the exhaust cam of a gas or oil-engine. Rise of valve, 1 inch; ratio of cam arm to valve arm of lever, 3 to 2.

9. Explain one method of lubricating the main bearings of an oil-engine.

10. Sketch an arrangement for lubricating the piston of a gas-engine.

APPENDIX.

Table of the Properties of Saturated Steam.

Absolute pressure in lbs. per square inch.	Temperature reading in degrees Fahrenheit.	Total Heat per pound of steam from water at 32° F.	Volume of one pound of steam in cubic feet.	Absolute pressure in lbs. per square inch.	Temperature reading in degrees Fahrenheit.	Total Heat per pound of steam from water at 32° F.	Volume of one pound of steam in cubic feet.
1	102·0	1113·0	330	46	275·7	1166·0	9·02
2	126·3	1120·5	172	47	277·0	1166·4	8·84
3	141·6	1125·1	118	48	278·3	1166·8	8·67
4	153·1	1128·6	89·6	49	279·6	1167·2	8·50
5	162·4	1131·5	72·5	50	280·9	1167·6	8·34
6	170·2	1133·8	61·1				
7	176·9	1135·9	52·9	55	286·9	1169·5	7·62
8	182·9	1137·7	46·6	60	292·6	1171·2	7·02
9	188·4	1139·4	41·8	65	297·8	1172·8	6·52
10	193·3	1140·9	37·8	70	302·8	1174·3	6·08
				75	307·4	1175·7	5·69
11	197·8	1142·3	34·6	80	311·9	1177·1	5·36
12	202·0	1143·6	31·9	85	316·1	1178·3	5·06
13	205·0	1144·7	29·6	90	320·1	1179·6	4·80
14	209·6	1145·9	27·6	95	323·9	1180·7	4·56
14·7	212·0	1146·6	26·4	100	327·6	1181·9	4·34
15	213·1	1146·9	25·8				
16	216·3	1147·9	24·3	105	331·2	1182·9	4·15
17	219·5	1148·9	23·0	110	334·6	1184·0	3·97
18	222·5	1149·8	21·8	115	337·9	1185·0	3·81
19	225·3	1150·6	20·7	120	341·1	1186·0	3·66
20	228·0	1151·5	19·7	125	344·1	1186·9	3·52
				130	347·1	1187·8	3·39
21	230·6	1152·3	18·8	135	350·0	1188·7	3·27
22	233·1	1153·1	18·0	140	352·8	1189·6	3·16
23	235·5	1153·8	17·3	145	355·6	1190·4	3·06
24	237·8	1154·5	16·6	150	358·2	1191·2	2·96
25	240·0	1155·2	16·0				
26	242·2	1155·9	15·4	155	360·7	1192·0	2·87
27	244·3	1156·5	14·9	160	363·3	1192·8	2·79
28	246·4	1157·1	14·4	165	365·7	1193·5	2·71
29	248·4	1157·7	13·9	170	368·2	1194·2	2·63
30	250·3	1158·3	13·5	175	370·5	1194·9	2·56
				180	372·8	1195·6	2·49
31	252·2	1158·9	13·1	185	375·1	1196·3	2·43
32	254·0	1159·5	12·7	190	377·3	1197·0	2·37
33	255·8	1160·0	12·3	195	379·5	1197·7	2·31
34	257·5	1160·5	12·0	200	381·6	1198·4	2·26
35	259·2	1161·0	11·7				
36	260·9	1161·5	11·4	205	383·7	1199·0	2·21
37	262·5	1162·0	11·1	210	385·8	1199·6	2·16
38	264·1	1162·5	10·8	215	387·8	1200·2	2·11
39	265·7	1163·0	10·5	220	389·8	1200·8	2·06
40	267·2	1163·5	10·3	225	391·8	1201·4	2·02
				230	393·8	1202·0	1·98
41	268·7	1164·0	10·1	235	395·7	1202·5	1·94
42	270·1	1164·4	9·83	240	397·5	1203·0	1·90
43	271·5	1164·8	9·61	245	399·3	1203·5	1·86
44	272·9	1165·2	9·40	250	401·1	1204·0	1·83
45	274·3	1165·6	9·21				

LOGARITHMS.

Explanation.—Logarithms are numbers so chosen that if a and b be any two quantities

$$\log a + \log b = \log ab$$
$$\log a - \log b = \log \frac{a}{b}$$

and therefore

$$\begin{aligned} \log a^2 &= \log a + \log a \\ &= 2 \log a \\ \text{or } \tfrac{1}{2} \log a^2 &= \log a \\ \log a^3 &= 3 \log a, \text{ etc.} \end{aligned}$$

Log 10 is taken as unity.

$$\begin{aligned} \therefore \log 10 &= 1 \\ \log 100 &= 2 \\ \log 1000 &= 3, \text{ etc.} \\ \log \cdot 1 &= -1 \\ \log \cdot 01 &= -2 \\ \log \cdot 001 &= -3, \text{ etc.} \end{aligned}$$

In the logarithm tables the first two figures of the number are given in the left-hand column, and the third figure across the top, thus—

$$\begin{aligned} \log 1\cdot 2 &= \cdot 0792 \\ \log 1\cdot 21 &= \cdot 0828, \text{ etc.} \end{aligned}$$

Allowance is made for a fourth figure, if there is one, by adding the corresponding quantity appearing under it in one of the nine right-hand columns, thus—

$$\begin{aligned} \log 1\cdot 204 &= \cdot 0792 + \cdot 0014 \\ &= \cdot 0806 \\ \log 1\cdot 458 &= \cdot 1614 + \cdot 0023 \\ &= \cdot 1637 \end{aligned}$$

In the anti-logarithm tables the positions of the numbers and logarithms are reversed.

Ex. 1.—To multiply 2934 by 3·12

$$2934 \times 3\cdot 12 = 1000 \times 2\cdot 934 \times 3\cdot 12$$
$$\log (2934 \times 3\cdot 12) = \log 1000 + \log 2\cdot 934 + \log 3\cdot 12.$$

From logarithm tables

$$\begin{aligned} \log 1000 &= 3\cdot 0000 \\ \log 2\cdot 934 &= \cdot 4669 + \cdot 0006 \\ \log 3\cdot 12 &= \cdot 4942 \\ \therefore \log (2934 \times 3\cdot 12) &= 3\cdot 9617 \end{aligned}$$

From anti-logarithm tables

$$\begin{aligned} 3 &= \log 1000 \\ \cdot 9617 &= \log (9\cdot 141 + \cdot 015) \\ \therefore \log (2934 \times 3\cdot 12) &= \log 9156 \\ \therefore 2934 \times 3\cdot 12 &= 9156. \end{aligned}$$

Ans.

Ex. 2.—To divide $3{\cdot}125$ by $7{\cdot}46$

$$\log 3{\cdot}125 = {\cdot}4942 + {\cdot}0007$$
$$= {\cdot}4949$$
$$\log 7{\cdot}46 = {\cdot}8727$$
$$\log \frac{3{\cdot}125}{7{\cdot}46} = \log 3{\cdot}125 - \log 7{\cdot}46$$
$$= {\cdot}4949 - {\cdot}8727$$
$$= 1{\cdot}4949 - {\cdot}8727 - 1$$
$$= {\cdot}6222 - 1$$
$$= \log (4{\cdot}188 + {\cdot}002) - \log 10$$
$$= \log \left(\frac{4{\cdot}190}{10}\right)$$
$$\therefore\ 3{\cdot}125 \div 7{\cdot}46 = {\cdot}4190.$$ *Ans.*

Ex. 3.—To find the cube root of ${\cdot}006859$

$$\tfrac{1}{3} \log {\cdot}006859 = \tfrac{1}{3} \log \frac{6{\cdot}859}{1000}$$
$$\therefore\ \tfrac{1}{3} \log {\cdot}006859 = \tfrac{1}{3} (\log 6{\cdot}859 - \log 1000)$$
$$= \tfrac{1}{3} ({\cdot}8363 - 3)$$
$$= {\cdot}2788 - 1$$
$$= \log \left(\frac{1{\cdot}9}{10}\right)$$
$$= {\cdot}19$$
$$\therefore\ \text{Cube root of } {\cdot}006859 = {\cdot}19.$$ *Ans.*

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170						4	9	13	17	21	25	30	34	38
						0212	0253	0294	0334	0374	4	8	12	16	20	24	28	32	37
11	0414	0453	0492	0531	0569						4	8	12	15	19	23	27	31	35
						0607	0645	0682	0719	0755	4	7	11	15	19	22	26	30	33
12	0792	0828	0864	0899	0934	0969					3	7	11	14	18	21	25	28	32
							1004	1038	1072	1106	3	7	10	14	17	20	24	27	31
13	1139	1173	1206	1239	1271						3	7	10	13	16	20	23	26	30
						1303	1335	1367	1399	1430	3	7	10	12	16	19	22	25	29
14	1461	1492	1523	1553							3	6	9	12	15	18	21	24	28
					1584	1614	1644	1673	1703	1732	3	6	9	12	15	17	20	23	26
15	1761	1790	1818	1847	1875	1903					3	6	9	11	14	17	20	23	26
							1931	1959	1987	2014	3	5	8	11	14	16	19	22	25
16	2041	2068	2095	2122	2148						3	5	8	11	14	16	19	22	24
						2175	2201	2227	2253	2279	3	5	8	10	13	15	18	21	23
17	2304	2330	2355	2380	2405	2430					3	5	8	10	13	15	18	20	23
							2455	2480	2504	2529	2	5	7	10	12	15	17	19	22
18	2553	2577	2601	2625	2648						2	5	7	9	12	14	16	19	21
						2672	2695	2718	2742	2765	2	5	7	9	11	14	16	18	21
19	2788	2810	2833	2856	2878						2	4	7	9	11	13	16	18	20
						2900	2923	2945	2967	2989	2	4	6	8	11	13	15	17	19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

Antilogarithms.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

USEFUL CONSTANTS.

In addition to the above logarithm tables the following list of constants is supplied to each candidate at the Board of Education examination in steam.

1 Inch = 25·40 millimetres.

1 Gallon = ·1604 cubic foot = 10 lbs. of water at 62° F.

1 Knot = 6080 feet per hour.

Weight of 1 lb. in London = 445,000 dynes.

One pound avoirdupois = 7000 grains = 453·6 grammes.

1 Cubic foot of water weighs 62·3 lbs.

1 Cubic foot of air at 0° C. and 1 atmosphere, weighs ·0807 lb.

1 Cubic foot of Hydrogen at 0° C. and 1 atmosphere, weighs ·00559 lb.

1 Foot-pound = $1·3562 \times 10^7$ ergs.

1 Horse-power-hour = 33,000 × 60 foot-pounds.

1 Electrical unit = 1000 watt-hours.

Joule's Equivalent to suit Regnault's H, is $\begin{cases} \text{774 ft.-lbs.} = \text{1 Fah. unit.} \\ \text{1393 ft.-lbs.} = \text{1 Cent. ,,} \end{cases}$

1 Horse-power = 33,000 foot pounds per minute = 746 watts.

Volts × ampères = watts.

1 Atmosphere = 14·7 lbs. per square inch = 2116 lbs. per square foot = 760 mm. of mercury = 10^6 dynes per sq. cm. nearly.

A column of water 2·3 feet high corresponds to a pressure of 1 lb. per sq. inch.

Absolute temp., $t = \theta°$ C. + 273°·7.

Regnault's H = 606·5 + ·305 $\theta°$ C. = 1082 + ·305 $\theta°$ F.

$p\, u^{1·0646} = 479$.

$\log_{10} p = 6·1007 - \frac{B}{t} - \frac{C}{t^2},$

where $\log_{10} B = 3·1812$, $\log_{10} C = 5·0881$.

p is in pounds per square inch, t is absolute temperature Centigrade.

u is the volume in cubic feet per pound of steam.

$\pi = 3·1416$.

One radian = 57·3°.

To convert common into Napierian logarithms, multiply by 2·3026.

The base of the Napierian logarithms is $e = 2·7183$.

The value of g at London = 32·182 feet per sec. per sec.

ANSWERS TO EXAMPLES.

EXAMPLES A. (p. 6).

1. 37·5 ft., 12·5 ft. **2.** 182·3 lbs., 60·8 lbs. **3.** 9 ft. 5 ins. **4.** 104 ft. 8 ins. **5.** 720 revs. **6.** 280 revs. **7.** 210 revs. **8.** 52·4 ft. **9.** 360 revs. **10.** 28·27 sq. ins. **11.** 5542 sq. ins. **12.** 247 tons. **13.** 9425 lbs. **14.** 17·7 lbs. **15.** 11·19 sq. ins. **16.** 9·81 sq. ins. **17.** 7·85 sq. ft. **18.** 1131 sq. ft. **19.** 854 sq. ft. **20.** 101·7 lbs. **21.** 3·83 cu. ft. **22.** 61 lbs. **23.** 3·27 tons. **24.** 662 cu. ft. **25.** 4·9 cu. ft.

EXAMPLES B. (p. 13).

1. 20 tons. **3.** £19 10 0. **4.** $3\frac{3}{7}$ years. **5.** 664 lbs. **9.** 35, nearly.

EXAMPLES I. (p. 28).

12. 7,680,000 ft. lbs. **13.** 243,200 ft. lbs. **15.** 1·57 E.H.P. **16.** 7·37 H.P. **17.** $\frac{3}{8}$ H.P. **18.** 1130·8 lbs., 848·1 ft. lbs. **19.** 11·3 H.P. **20.** 136 I.H.P. **21.** 483 I.H.P. **22.** ·32. **23.** 177 strokes. **24.** 50·9 lbs. per sq. in., 59·9 lbs. per sq. in.

EXAMPLES II. (p. 44).

4. (*a*) The larger. (*b*) The smaller. **5.** 25 lbs. per sq. in. **7.** 18·8 lbs. per sq. in. **8.** 50, 33·3, 25 and 20 lbs. per sq. in. **14.** 23·79 I.H.P. **16.** 49,500, 24,750, 16,500, 12,375 lbs. **17.** 126 lbs. per sq. in. (nearly). 109 lbs. per sq. in. 24,416 ft. lbs. **18.** 88 lbs. per sq. in. 2,878 ft. lbs.

EXAMPLES III. (p. 60).

8. 2182 lbs. **9.** At least 23. **13.** 2450 lbs. **21.** ·64 ft. per sec. per sec. 38·4 ft. per sec. (26·2 miles per hr.). **22.** 2904 lbs.

EXAMPLES IV. (p. 70).

9. $1\frac{1}{8}$ ins. dia.

EXAMPLES V. (p. 85).

2. $\frac{3}{4}$ in. **3.** 2 ins. **4.** $1\frac{3}{4}$ ins. **8.** 31 and 28 lbs. per sq. in. **9.** 39 and 38 lbs. per sq. in. **11.** (*a*) 84°. (*b*) ·55 of stroke from back dead point.

EXAMPLES VI. (p. 98).

2. c. **7.** 7 ft. $7\frac{1}{2}$ ins. **8.** (*a*) 4,065,600 ft. lbs. (*b*) 16,262,400 ft. lbs.

EXAMPLES VII. (p. 112).

1. 1440 lbs. 4. 28·5 to 1. 18. ⅜ in. 19. ·57.

EXAMPLES VIII. (p. 125).

3. 1⅓ ins. 6. 294 lbs. 7. 43⅝ lbs. 8. 14 lbs. 9. 62·9 lbs. 11. 74 strokes. 19. 141·3 lbs. 20. 272 gallons (if pump is single-acting). 21. 1375 lbs.

EXAMPLES IX. (p. 144).

5. 37° C. 6. Temp. in London is the higher by ·6° F. 8. 15,680,000 Th. U. 12. 14,700 Th. U. per lb. 13. ·97 ton. 14. Oil. 16. 99·9° F. 17. 19·3 lbs. per hour. 18. 65 %. 19. 9·6 lbs. 21. 978 Th. U. 22. 9892 Th. U. are given to water, 2160 Th. U. pass up chimney per lb. of coal. 23. 1125·5 Th. U. 13·3 lbs. 24. Heat given to water per lb. of fuel, (1) 10,571 Th. U., (2) 10,964 Th. U.

EXAMPLES X. (p. 156).

2. 15,323 ft. lbs. 3. 60,800 Th. U. (nearly). 4. 426 Th. U. 5. ·086. 6. ·047. 7. 1470 lbs. 12. Heat usefully employed, 7·1 %; heat lost in boiler and chimney, 31·5 %; heat lost in engine, 60·6 %; heat lost in dynamo, etc., ·8 %. 13. 8·60, ·274, ·063, 5·86. 14. ·085, ·141, ·208. 15. 312·4° C. 16. 635·55 Th. U.

EXAMPLES XI. (p. 166).

7. 24·4 lbs. 8. 97° F. 9. 96·6° F. 10. 126° F. 11. 210 lbs. 12. 228 tons. 14. 18,990 lbs.

EXAMPLES XII. (p. 173).

2. 53·4 lbs. 9. 5·625. 11. Locomotive, 150° F.; marine engine, 215° F. 13. 11·52. 14. H.P. 1618, I.P. 1672, L.P. 1658.

EXAMPLES XIII. (p. 186).

8. 11·5 lbs. 11. 11·8 H.P.

EXAMPLES XIV. (p. 201).

4. 76·8 E.H.P., 177·9 I.H.P. 5. At 10 knots, thrust = 20,000 lbs. E.H.P. = 614; I.H.P. = 1054. 9. 37·5 sq. ft. 13. 5 tons. 14. 98 lbs. per sq. in. 15. 960 ft. per minute.

EXAMPLES XV. (p. 211).

7. ·85 c. ft., 1·22 c. ft.

EXAMPLES XVI. (pp. 227, 228).

1. Cost for gas-engine four times that for steam-engine. 7. 11·6 I.H.P. 8. Heat converted into work, 16·3 %; Heat given to jacket-water, 32·5 %. 9. 334° C. 10. 73·8 lbs. per sq. in.

EXAMINATION PAPERS

A.

1. Describe, with sketches, only *one* of the following (*a*), (*b*), (*c*), or (*d*):—
   (*a*) Any kind of cross-head, showing ends of piston-rod and connecting-rod and guide.
   (*b*) A gas or oil engine cylinder, showing valves and piston.
   (*c*) A surface condenser, showing the stays and the attachment of the tubes.
   (*d*) An air-pump, showing foot, bucket, and delivery valves.

2. Describe, with sketches, only *one* of the following (*a*), (*b*), (*c*), or (*d*):—
   (*a*) Locomotive cylinders, and how they are fastened to the side frames.
   (*b*) A steam or gas engine governor, and how it regulates.
   (*c*) A spirit or oil engine for a motor car, showing how it drives the car and how it works.
   (*d*) The frame of a marine engine, showing how the pumps are worked.

3. Answer only *one* of the following (*a*), (*b*), or (*c*):—
   Describe how you would experimentally determine—
   (*a*) How the pressure and temperature of steam depend upon one another. Why must there be no air present?
   (*b*) The calorific power of any kind of burning gas.
   (*c*) The latent heat of steam.

4. State the following amounts of energy in foot-pounds:—
   A weight of one ton which may fall vertically 10 feet.
   3 lbs. of water raised 20° Centigrade.
   One horse-power hour.
   3 watts for 200 hours. (15)

5. Draw the compression, ignition, and expansion part of a gas-engine diagram. If the volumes and pressures at four points on the diagram, to any scales whatsoever, are represented by—

Points	*A*	*B*	*C*	*D*
Volumes	5	1·5	2	4
Pressures... ...	1	4	10	3

and if at the point *A* we know that the temperature is 127 C., what are the temperatures at the other points? Tabulate the results.

6. A steam electric generator on three long trials, each with a different point of cut-off on steady load, uses the following amounts of steam per hour for the following amounts of power :—

Lbs. of steam per hour ...	4,020	6,650	10,800
Indicated horse-power ...	210	480	706
Kilowatts produced	114	290	435

Find the indicated horse-power and the weight of steam used per hour when 330 kilowatts are being produced.

7. Steam enters a cylinder at 150 lbs. (absolute) per square inch. It is cut off at one-fourth of the stroke and expands according to the law "pv constant." Find the average pressure (absolute) in the forward stroke. If the back pressure is 17 lbs. (absolute) per square inch, what is the average effective pressure? If the area of the cross-section of the cylinder is 126 square inches, and the crank is 11 inches long, what work is done in one stroke? Neglecting clearance and condensation, what volume of steam enters the cylinder per stroke?

8. Using the formula in the table of useful constants furnished you, find the volume of 1 lb. of the steam admitted to the cylinder of Question 7. What weight of steam is actually admitted to that cylinder per stroke?

If you do not care to use the formula, use the following information and squared paper: Steam at 150 lbs. pressure is at 181° C., and the following numbers are known:—

Temperature	175° C.	180° C.	185° C.
Volume in cubic feet of 1 lb. of steam	3·419	3·065	2·756

9. Sketch a simple slide valve placed symmetrically over the cylinder ports, and in dotted lines show it at the beginning of a stroke of the engine. What do we mean by outside lap, inside lap, lead of valve, and advance of eccentric?

10. If cut-off takes place on both sides of a piston when the crank makes an angle of 90° with the dead point, (1) assuming connecting-rod infinitely long, (2) assuming connecting-rod four times length of crank, find in each case for each side of piston the fraction of stroke at which cut-off takes place.

11. We endeavour to prevent condensation in the cylinder of a steam-engine, (*a*) by a separator, (*b*) by superheating, (*c*) by drainage from the cylinder, (*d*) by steam-jacketing, (*e*) by high speed. Explain how each of these methods tends to effect our object.

12. Using the formula in the table of useful constants furnished you find how much heat was given to each pound of feed water at 20° C. to convert it into the steam which is admitted to the cylinder of Question 8, if that admitted steam is at 181° C. and is not wet.

B.

1. Describe, with sketches, only *one* of the following (*a*), (*b*), (*c*), or (*d*):—
   (*a*) A piston slide valve and its seat, showing packing and ports.
   (*b*) Any engine, steam, spirit, or oil, used on motor cars.
   (*c*) Any link motion or other reversing gear to work a slide valve with which you are acquainted. State exactly what is the effect of altering the gear.
   (*d*) Either a Geipel or Sirius or Turnbull or Lancaster steam trap.

2. Describe, with sketches, only *one* of the following (*a*), (*b*), or (*c*):—

(*a*) A double-ended cylindric marine boiler; the usual positions of joints of plates and of stays to be indicated. Where and why is leakage probable under forced draught?

(*b*) Any water-tube boiler; the general construction to be clearly shown: some one part shown in good detail and more carefully described.

(*c*) A steam boiler for a traction engine or a motor car, the fuel being oil or spirit. Describe carefully any appliance necessary in this boiler which is not usually found on a stationary boiler.

3. Answer only *one* of the following (*a*), (*b*), or (*c*). How would you experimentally determine—

(*a*) The latent heat of steam at atmospheric pressure? Why is it more difficult to measure the latent heat at, say, two atmospheres?

(*b*) The total heat obtainable from the burning of one pound of kerosene?

(*c*) How the rate of passage of heat from hot gas inside a tube to water outside the tube depends upon the velocity of gas along the tube?

4. State the following amounts of energy in foot-pounds:—

A weight of 1·6 tons may fall vertically 12 feet.

The kinetic energy of a body of 100 lbs. moving at 1,200 feet per second.

2·4 lbs of water raised from 50° F. to 80° F.

The latent heat of steam at atmospheric pressure

One horse-power hour.

2·3 kilowatts for 5 hours.

The energy given to a mass of fluid at 150° C., increasing its entropy by the amount of 0·56 ranks, its temperature keeping constant.

5. Steam of 150 lbs. per square inch (absolute) is cut off at $\frac{1}{3}$ stroke, and expands according to the law *pv* constant. Find the average pressure in the forward stroke, using squared paper. The back pressure is 18 lbs. per square inch, what is the effective pressure on the piston? The piston is 15 inches diameter; crank 1 foot; two strokes in the revolution; 120 revolutions per minute; find the work in one revolution and the H.P.

6. At an electric-power station, 4,150 units of electric energy were sold in 24 hours, the coal consumed being 16,200 pounds. And on another occasion 2,489 units were sold in the 24 hours, the coal consumption being 12,880 pounds. It is known that if units of electricity and weight of coal are plotted on squared paper, the points will lie fairly well in a straight line. The maximum output is 25,000 units. Find the coal consumed in the 24 hours,

when there are the daily outputs of 8, 16, 24, and 50 per cent. of the maximum. In each case what is the coal per unit? Tabulate your answers.

7. Sketch the compression, ignition, and expansion parts of a gas engine diagram. If the volumes and pressures at four points on the diagram, to any scales whatsoever, are represented by—

Points	*A*	*B*	*C*	*D*
Volumes	6	1·7	2	4·5
Pressure	1	5	13·8	3·2

and if at the point *A* we know that the temperature is 140° C., what are the temperatures at the other points? Tabulate your results.

8. Sketch the section of a simple slide valve placed symmetrically over the ports, and, in dotted lines, show it at the beginning of the stroke of the engine. What do we mean by *outside lap*, *inside lap*, *lead of valve*, and *angular advance?*
Draw another view of the valve, showing its face.

9. A piston and rod and cross-head weigh 330 lbs. At a certain instant, when the resultant total forces due to steam pressure is 3 tons, the piston has an acceleration of 370 feet per second per second in the same direction. What is the actual force acting at the cross-head?

10. A vessel is filled by 100 tons of water at 210° C. How much steam must be taken away just dry at 175° C. through a reducing valve for the temperature of the remainder to become 175° C.? You are given that the latent heat of steam at 175° C. is 482·7 centigrade units.

11. There is a balance weight of 180 lbs. at a distance of 3·4 feet from the centre, and another weight of 150 lbs. at a distance of 2·56 feet from the centre, in a direction at right angles to the first, both on the same driving-wheel of a locomotive. Find the amount and position of any single weight which would have the same balancing effect as these two.

12. Describe, with sketches, a loaded Watt governor. Why is a load used?

13. Describe, with sketches, how lubrication of the various parts of an engine (not encased) is now usually performed.

C.

1. Describe, with good sketches, some one important detail of a modern steam or internal combustion engine with which you are well acquainted. If, for example, the crank-pin and the end of a connecting-rod be shown, it is of no use merely indicating the existence of a bolt and nut; the bolt and nut, and the method of locking the nut, must be clearly shown. Again, it is no use making a sketch of so much of any engine that details cannot be clearly sketched. For example, a whole governor with its gear would be too much, but certain parts may be chosen.

   This question is to test your knowledge of details and your power to sketch.

2. Describe, with good sketches, some one important part of any kind of boiler. For example:—a fitting like a safety valve; the staying of the fire-box crown of a locomotive; the arrangement of a furnace; a feed-water heater; gauge glass and connections.

   The remarks in Question 1 apply here also.

3. In connection with the steam or gas or oil or spirit engine work with which you are acquainted there is testing of some sort to be done requiring careful measurement of work or heat. For example:—finding the calorific power of coal, gas, or oil; finding the latent heat of steam; or how its pressure depends upon temperature; or finding the wetness of steam during an engine test; comparing the power of an engine and the quantity of heat or of steam, gas, or oil used per hour. Describe, with sketches, some one such test.

   (Should you choose to answer also Question 10, there must be no repetition.)

4. Steam enters a cylinder at 140 lbs. pressure (absolute) per sq. inch; is cut off at 0·35 of the stroke and expands according to the law "pv constant." Neglect clearance and cushioning, and draw the hypothetical diagram usually taken. Back pressure 17 lbs. per sq. inch. Find the effective pressure. Area of piston, one square foot; stroke, 2 feet. What is the work done in one stroke? How many cubic feet of steam entered the cylinder? What is the work done per cubic foot?

5. An engine whose speed and cut-off do not alter, uses W lb. steam per hour when its actual horse-power is P, and W and P have been carefully measured during three long tests.

P	152	110	56
W	3190	2630	1850

What is the probable *W* when *P* is 125 horse-power? In each of the four cases find the steam used per horse-power hour.

6. What is Regnault's total heat of steam at 170° C.? Use the formula on the outside page of the tables given you. State exactly what you mean by this total heat. How much of it is given to the water? How much is called latent heat of steam? Give these two answers for steam at 100° C.

7. Sketch a simple slide valve showing cylinder ports and no more of the cylinder; show the valve in its mid position. Show in dotted lines the position of the valve when the piston has just begun its stroke. What do we mean by outside lap of a valve, inside lap, advance, and half travel? How do these affect the distribution of steam?

8. A link motion or other gear for a slide valve will reverse an engine, but suppose we do not reverse the engine; suppose we only change from say full to half gear; state clearly what it is that is really effected by the change. Sketch also the probable change in the indicator diagram.

9. What is the cause of *priming* in boilers? Even if the boiler does not prime, why may wet steam reach the cylinder? What may be done to prevent it? Even if only dry steam enters the cylinder, why may there be condensation on admission? Why is this harmful? What may be done to prevent it?

10. Describe the construction of an indicator, and how it is used. Give a sketch of a specimen indicator diagram from a steam, gas, or oil engine, and describe what each part of the diagram means.

11. Why is an engine *balanced?* Describe generally any method of balancing the rotating parts that is known to you.

    Imagine a long railway truck containing an invisible caged lion on a level track; axle bearings frictionless; imagine the lion to walk backwards and forwards to the limits of its cage, what would an outsider observe? Now suppose the wheels of the wagon blocked, what occurs?

12. State very clearly what are the conditions that must be satisfied for good combustion in a furnace, and for the efficient communication of heat from the hot gases to the water of a boiler.

D.

1. Answer and illustrate by good sketches either (*a*) or (*b*), but not both :—
   (*a*) In reference to any modern example of a steam, gas, oil, or spirit engine you like to select, how is leakage prevented past the piston? Also past the piston-rod if a steam-engine is chosen?
   (*b*) Describe the construction of a steam-engine cylinder, showing the ports and the steam inlet and outlet, but omitting the covers of the cylinder and steam chest.

2. Answer and illustrate by good sketches either (*a*) or (*b*), but not both, in reference to the type of modern steam-boiler with which you are best acquainted :—
   (*a*) Show the arrangement for feeding the boiler with water under pressure.
   (*b*) Explain how the steam is brought to the cylinder as dry as possible. Describe a valve for shutting off the supply of steam.

3. Describe how you would test a boiler for strength, *or* an indicator for accuracy, *or* a feed-water meter. Choose only one of these.

4. What heat is given to 1 lb. of water at 0° C. to convert it into dry saturated steam at 180° C.? Use the formula on the outside page of the tables given you. How much of this is given to it as water to raise its temperature, and how much is latent heat? If instead of being at 0° C. it had been water at 30° C., how much heat would have been needed?

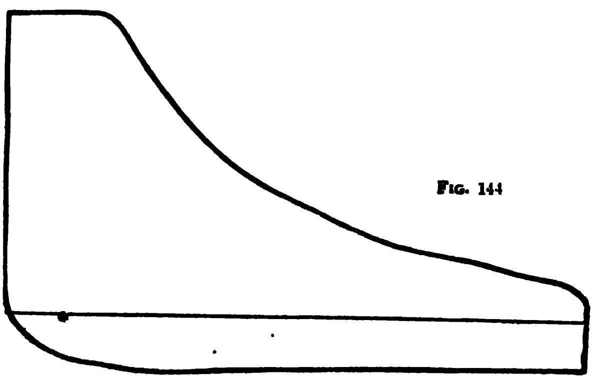


FIG. 144

5. Figure 144 shows an indicator diagram with its atmospheric line, from a cylinder 15 inches diameter, 2 feet stroke. The scale of the diagram is known from the fact that the highest *gauge* pressure is 75 lbs. per square inch. Find the effective average pressure and the work done in one stroke.

6. Describe with sketches any method known to you of admitting and exhausting steam to and from the two ends of a cylinder. You must show that you know how the contrivance admits and releases before the ends of the stroke and allows expansion and cushioning.

7. If a locomotive of 1,200 indicated horse-power uses 38 lbs. of feed-water per hour per indicated horse-power; in a journey of two and a half hours, what is the total amount of feed-water? If every pound of coal produces 9 lbs. of steam, what is the total weight of coal burnt on the journey? If the mechanical efficiency of the engine is 0·85, what is the power actually spent in overcoming the resistance of the engine and train?

8. The crank-shaft of a gas-engine is giving out steadily 20 horse-power at an average speed of 150 revolutions per minute. How many foot-pounds is this per cycle (of two revolutions)? About how much of this must be stored and unstored by the fly-wheel if there are 75 explosions per minute?

9. Describe with sketches how any governor keeps the speed of an engine fairly constant. What is meant by *hunting?*

10. What occurs to the coal and its constituents in the furnace of any boiler? Choose some boiler with which you are well acquainted. What becomes of the heat developed? Trace the products of combustion along the flues as they get cooler, and say what is the nature and state of these products, and why the heat is leaving them.

11. In comparing the following methods of generating heat, pay attention only to cost, leaving convenience and other matters out of account.

 1 lb. of average coal gives out 8,500 centigrade pound heat units.

 1 cubic foot of average London gas gives out 380 centigrade pound heat units.

 A Board of Trade unit of electrical energy is 1⅓ horse-power hours.

 How much heat is generated by one ton of coal? If the gas costs three shillings per thousand cubic feet; if the Board of Trade unit costs sixpence, what is the cost in these two cases of the amount of heat given out in burning one ton of coal?

12. From a shaft driven by a steam-engine the actual work in foot-pounds delivered per cubic foot of steam admitted to the cylinder is

$$144\left\{p_1(1+\log_e r)-r(p_3+f+m)\right\}$$

when p_1, the initial pressure, is 100 lbs. per square inch, where p_3, the back pressure, is 17 lbs. per square inch, where f represents the friction of the engine and shafting and is 14, where m represents missing water and bad effect of clearance and is 14.

Calculate this for such values of r as 3, $2\frac{1}{2}$, 2, $1\frac{1}{2}$, and plot on squared paper to find the best cut-off.

E.

1. Describe, with sketches, one, and only one, of the following, (*a*), (*b*), (*c*), (*d*), or (*e*) :—
   - (*a*) The piston of a large steam-engine, its packing and fastening to the piston-rod.
   - (*b*) The piston, piston-rod and cross-head of a locomotive.
   - (*c*) The cylinder of a gas-engine.
   - (*d*) The vanes and mouthpieces of an impulse steam-turbine.
   - (*e*) The cylinder, valves and igniting arrangement of a petrol engine.

2. Describe, with sketches, one, and only one, of the following, (*a*), (*b*), (*c*), or (*d*) :—
   - (*a*) The smoke box of a locomotive showing exhaust steam-pipe and cylinder fastenings.
   - (*b*) A marine safety valve, or a dead-weight safety valve, showing seating block.
   - (*c*) The general arrangement of any water tube boiler, some one detail being entered into fully.
   - (*d*) A Bourdon pressure gauge.

3. How would you experimentally determine the calorific value of a fuel? choose some one only, solid, liquid or gaseous.

4. Describe, with sketches, how you would take an indicator diagram of a steam-engine or a gas-engine. Sketch a possible diagram and explain how you would calculate the indicated horse-power. What information is necessary?

5. The heat required to convert a pound of water at 0° C. into a pound of steam at θ° C. is

$$H = 606{\cdot}5 + 0{\cdot}305\,\theta.$$

How much is this if the steam is at 180° C.? How much of this is *latent heat?*

If the water had been at 40° C. to begin with, what total heat was needed?

6. Draw a slide valve in its mid position, and in dotted lines show its position at the beginning of the stroke of the piston.
Explain how it distributes steam. What do we mean by half-travel, angular advance and lap of a valve?

7. If a piston with its rod weighs 250 lb., and if at a certain instant when the resultant total force due to steam pressures is 3 tons the piston has an acceleration of 320 feet per second per second in the same direction what is the actual force acting on the cross-head?

8. At an Electric Light Station: On full power (or load factor 100 per cent.) the output is 6,000 kilowatts, the feed water being 132,000 lb. per hour. When the output is 1,200 (or load factor 20 per cent.), the feed water is 53,000 lb. per hour. Plot power and water on squared paper and assume a straight line law. What is the water per hour when the load factor is 10 per cent.? (that is, the output is 600 kilowatts). Tabulate the numbers. State in each case the water per hour per kilowatt.

9. How do we try to prevent condensation in a cylinder? If any of the methods serves some other good object, state it.

10. One pound of a fuel contains 0·8 lb. of carbon and 0·15 lb. of hydrogen and no free oxygen or nitrogen: what weight of oxygen is needed for complete combustion? what weight of air?

11. Choose any kind of boiler. Explain how by its construction, 1st, the combustion is made as complete as possible, 2nd, as much of the heat as possible is given to the water. You need not speak of careful firing.

12. Explain why both the flywheel and governor are needed to regulate or govern the speed of an engine.

13. State in foot-pounds the following amounts of energy:—(*a*) A weight of 40 tons raised 30 feet; (*b*) a projectile of 40 lb. moving at 2,000 feet per second; (*c*) 3·4 horse-power-hours; (*d*) 2·5 kilowatt-hours; (*e*) the calorific energy of one lb. of average coal which is 8,370 Centigrade heat units.

F.

1. Describe, with good sketches, one, and only one, of the following, (*a*), (*b*), (*c*) or (*a*):—
   (*a*) The crank shaft bearing of a horizontal or vertical engine.
   (*b*) The crank axle of an inside cylinder locomotive.
   (*c*) The piston of a gas or petrol engine, showing the packing, and the pin to which the connecting rod is attached.
   (*d*) The rotating part of a Parson's or other steam turbine, showing how the vanes are fixed.

2. Describe, with good sketches, one, and only one of the following, (*a*), (*b*), (*c*), (*d*) or (*e*) :—
   (*a*) A steam stop valve of the screw-down type.
   (*b*) A locomotive regulator valve of any type.
   (*c*) Two forms of boiler stays, stating the use of each.
   (*d*) The front plate of a Lancashire, Cornish, or return tube marine boiler, showing how the boiler shell is attached.
   (*e*) The carburetor of a petrol or oil engine.

3. With a small experimental boiler you are finding the pressure of steam when its temperature is, say, 100° C., 110° C., 120° C., &c. Show, with sketches, exactly how you would proceed. In what way does the presence of air with the steam spoil your results?

4. State the following amounts of energy in foot-pounds :—
   (*a*) A weight of 35 tons may fall vertically 15 feet.
   (*b*) The kinetic energy of a projectile of 60 lbs. moving at 2,000 feet per second.
   (*c*) The calorific energy of 1 lb. of coal, 8,500 Centigrade pound heat units.
   (*d*) 30 lbs. of water raised from 40° F. to 103° F.
   (*e*) One horse-power hour.
   (*f*) One kilowatt hour.

5. It used to be thought that by cutting off earlier and earlier in the stroke, we got better and better results. Why is this untrue? It used to be that the slide valve was never found on economical engines; why is it now in use on many large and economical engines?

6. The mean effective pressure on the piston, both in the forward and back strokes, is 62 lbs. per square inch; cylinder, 18 inches diameter; crank, 18 inches long. What is the work done in one revolution?

7. A pound of oil contains 0·85 lb. of carbon and 0·15 lb. of hydrogen. What weight of oxygen is sufficient to produce CO_2 and H_2O by combustion? Take the atomic weights of C, 12; of O, 16; of H, 1. If 1 lb. of oxygen is contained in 4·35 lbs. of air, how many pounds of air are needed for complete combustion?

8. A slide valve is worked directly from an eccentric. The advance is 30°. When the main crank has moved 20° from the line of centres, show the position of the eccentric crank. The half travel being 3 inches, mark off this radius and drop a perpendicular on the line of centres; what have you thus found?

9. A formula for Regnault's total heat H will be found on the tables supplied to you; it is the total heat which must be given to 1 lb. of water at 0° C. to raise its temperature as water to θ° C., and then to convert it all into steam at θ° C. What is the heat which must be given to 1 lb. of water at 40° C. to convert it into steam at 170° C.?

10. A boiler furnace fire is about 12 inches thick. What do we know as to the way in which the combustion is going on at various places in the coal and above it and in the space just on the furnace side of the flues? Take any state you please; just before fresh coal is supplied or after, but you must say what the conditions are.

11. F lb. is the outward radial force on each ball of a governor required to keep it in equilibrium at the distance r feet from the axis when not revolving. The following are for the extreme cases:—

r	F
0·5	100·1
0·7	144·6

The weight of each ball being 10 lbs., what is the centrifugal force of each at n revolutions per minute, the radius being r.

What are the speeds for the above values of r when the governor is revolving?

12. In a gas-engine cylinder where $v = 2·2$ and $p = 14·72$ it was known that the temperature was 130° C. What is the temperature when $p = 122$ and $v = 1·2$?

13. The total heat, that is, the heat H required to convert a pound of water at 0° C. into a pound of wet steam at θ° C., having a dryness fraction x, is

$$H = \theta + xL.$$

where L is the latent heat of 1 lb. of dry saturated steam. If wet steam 90 per cent. dry (that is, $x = 0·9$) at 203·3 lbs. per square inch, is throttled by passing through a non-conducting reducing valve to 101·9 lbs. per square inch, what is its dryness at the lower pressure? Remember that H is the same for the two kinds of steam; it keeps constant when steam is throttled.

p	θ	L
203·3	195	468·0
101·9	165	489·9

G.

1. Describe, with sketches, one, and only *one*, of the following, (*a*), (*b*), (*c*), (*d*), or (*e*):—
   (*a*) Any form of governor.
   (*b*) A large air-pump for a steam-engine.
   (*c*) The crank axle of a locomotive, showing the eccentric sheaves, the direction of the centre of each sheave being shown relatively to the directions of the cranks.
   (*d*) An engine used on any kind of motor-car.
   (*e*) The rotating part of any steam-turbine, showing how the vanes are fixed.

2. Describe, with sketches, only *one* of the following, (*a*), (*b*), (*c*), or (*d*):—
   (*a*) The fire-box of a locomotive, showing how it is stayed. Give larger sketches of a few details.
   (*b*) Any important part of any water-tube boiler.
   (*c*) Any form of safety-valve now in common use.
   (*d*) The carburettor of a petrol-engine.

3. Describe, with sketches, how you would experimentally determine one (and only *one*) of the following, (*a*), (*b*), (*c*), or (*d*):—
   (*a*) The law connecting pressure, volume, and temperature of a quantity of air.
   (*b*) The heat required to convert 1 lb. of water at 0° C., into dry saturated steam at, say, 100 lbs. per square inch.
   (*c*) The dryness of steam leaving a boiler.
   (*d*) The calorific power of a gas, or an oil, or petrol.

4. State the following amounts of energy in foot-pounds:—
   (*a*) The kinetic energy of the rim of a fly-wheel whose weight is 3 tons, average velocity 75 feet per second.
   (*b*) The calorific energy of one cubic foot of producer gas 95 centigrade heat units.
   (*c*) 25 lbs. of water raised from 10° C. to 40° C.
   (*d*) Twenty horse-power during 3 minutes.
   (*e*) Three B.O.T. units, that is 3 kilowatt-hours.

5. Steam enters a cylinder at any initial (absolute) pressure p_1, it is cut off at $\frac{1}{4}$ of the stroke. What is the average pressure during the stroke? It is some fraction of p_1. Assume the hypothetical diagram, no clearance, and an expansion law pv constant.

   Apply your answer to the cases where p_1 is 100, 80, and 60. If the back pressure is 17, what is the mean effective pressure in each case?

   The area of the piston is 300 square inches, crank 2 feet, two strokes in a revolution; what is the work done in one revolution in each of the above cases? Tabulate your answers.

6. Two strokes in a revolution, area of piston 300 square inches, crank 2 feet. What is the volume (neglecting clearance) of

steam admitted if the cut-off is at $\frac{3}{8}$ of the stroke? If the initial pressure is 100, or 80, or 60 lbs. per square inch, what weight of steam is used in one stroke (assuming no condensation, no clearance)? What weight is used in one revolution?

	100	80	60
Volume in cubic feet on 1 lb. of steam	4·356	5·37	7·03

7. The area of a petrol-engine diagram is (using the planimeter which subtracts and adds properly) 4·12 square inches, and its length (parallel to the atmospheric line) is 3·85 inches; what is the average breadth of the figure? If 1 inch represents 70 lbs. per square inch, what is the average pressure? The piston is 3·5 inches in diameter with a stroke of 4 inches. What is the work done in one cycle? If there are 800 cycles per minute, what is the horse-power?

8. A formula for Regnault's total heat H will be found on the tables supplied to you; it is the total heat which must be given to 1 lb. of water at 0° C. to raise its temperature as water to θ° C., and then to convert it all into steam at θ° C. What is the heat which must be given to 1 lb. of water at 0° C. to convert it into steam at 150° C.? What amount of this was required to heat the water before any of it was converted into steam? What name is given to the remainder, and how much is it?

9. Why do we admit air by the fire door as well as from the ashpit through the grate of a boiler furnace?

10. Sketch and describe any form of steam or gas engine indicator.

11. What is the formula for centrifugal force F lbs. in terms of radius r feet, mass m or $\frac{w}{32\cdot 2}$, and n revolutions per minute? Given F, r, and m, show how we find n. If F has the following values for the given values of r, and $w = 9\cdot 66$ lb., find n in each case.

r feet.	F pounds.
0·6	87
0·8	120

12. Sketch the ports and a simple slide-valve in its mid position. In dotted lines show the valve at the beginning of a stroke of the piston. What do we mean by lap, lead, and advance of a valve?

13. What methods are taken to prevent condensation of steam in the cylinder of an engine? Why does such condensation tend to take place?

INDEX.

T

PRINTED AT THE BURLINGTON PRESS, FOXTON, NEAR CAMBRIDGE, ENGLAND

Chemistry—*continued.*

Chemical Calculations. By H. W. BAUSOR, M.A., F.C.S., A.I.C. 2s. 6d. ***Advanced Course.*** 1s. 6d.

Systematic Practical Organic Chemistry. By G. M. NORMAN, B.Sc., A.R.C.S., F.C.S. *Second Edition.* 2s. 3d.

Qualitative Determination of Organic Compounds. By J. W. SHEPHERD, B.Sc. 9s. 6d.

The Elements of Organic Chemistry. By E. I. LEWIS, M.A., B.Sc., F.C.S. 4s.

Introduction to the Carbon Compounds. By R. H. ADIE, M.A., B.Sc. 3s.

Physics.

The Tutorial Physics. By R. W. STEWART, D.Sc., EDMUND CATCHPOOL, B.Sc., R. W. HUTCHINSON, M.Sc., A.M.I.E.E., C. J. L. WAGSTAFF, M.A., W. R. BOWER, B.Sc., A.R.C.S., and JOHN SATTERLY, D.Sc., M.A.

A series of books suitable for University Classes and for the highest forms of secondary schools.

I. Sound, Text-book of. By EDMUND CATCHPOOL, B.Sc. *Fifth Edition.* 6s. 6d.

II. Heat, Higher Text-book of. By Dr. STEWART. *Second Edition.* 7s. 6d.

III. Light, Text-book of. By Dr. STEWART and Dr. SATTERLY. *Fifth Edition.* 6s. 6d.

IV. Magnetism and Electricity, Advanced Text-book of. By R. W. HUTCHINSON, M.Sc., A.M.I.E.E. In Two Vols. *Second Edition.* 12s. 6d.

V. Properties of Matter. By C. J. L. WAGSTAFF, M.A. *Third Edition.* 5s.

VI. Practical Physics. By W. R. BOWER, B.Sc., A.R.C.S., and JOHN SATTERLY, D.Sc., M.A. *Second Edition.* 7s.

Magnetism and Electricity, Intermediate Text-book of. By R. W. HUTCHINSON, M.Sc., A.M.I.E.E. 9s. 6d.

Heat, Theoretical and Practical, Text-book of. By Dr. STEWART and Dr. SATTERLY. 6s. 6d.

Heat, New Matriculation. By Dr. STEWART. *Second Edition.* 4s.

Light, New Matriculation. By Dr. STEWART. 4s.

Sound, New Matriculation. By Dr. STEWART. 4s.

Magnetism and Electricity, Matriculation. By R. L. JUDE, D.Sc., M.A., and JOHN SATTERLY, D.Sc., M.A. *Second Edition.* 6s. 6d.

Physics—*continued.*

Heat, Senior. By Dr. STEWART and Dr. SATTERLY. *Second Edition.* **5s.**

Heat, Junior. By Dr. SATTERLY. *Second Edition.* **2s. 6d.**

Sound and Light, Senior. By Dr. STEWART and Dr. SATTERLY. **6s.**

Sound and Light, Junior. By Dr. STEWART and Dr. SATTERLY. **3s. 6d.**

Magnetism and Electricity, Senior. By Dr. JUDE and Dr. SATTERLY. *Second Edition.* **6s. 6d.**

Magnetism and Electricity, Junior. By Dr. JUDE and Dr. SATTERLY. *Second Edition.* **3s. 6d.**

Junior Experimental Science. By W. M. HOOTON, M.A., M.Sc., F.I.C. *Second Edition.* **3s. 6d.**

Experimental Science, Preliminary Course of. By W. M. HOOTON, M.A., M.Sc., F.I.C. **2s. 6d.**

Elementary Science, General. Edited by WM. BRIGGS, LL.D., M.A., B.Sc., F.R.A.S. *Fourth Edition.* **5s.**

Mechanics and Physics, An Introductory Course of. By W. M. HOOTON, M.A., M.Sc., F.I.C., and ALFRED MATHIAS. **2s. 6d.**

Chemistry and Physics for Botany Students. By E. R. SPRATT, D.Sc., F.L.S., A.K.C. **3s.**

Worked Problems in Heat and Heat Engines. By Dr. STEWART. *Rewritten and Enlarged.* **1s. 6d.**

Biology.

Text-book of Botany. By J. M. LOWSON, M.A., B.Sc., F.L.S. *Sixth Edition.* **9s. 6d.**

Lowson's Text-book of Botany. (Indian Edition.) Revised and adapted by BIRBAL SAHNI, D.Sc., M.A., Professor of Botany at the University of Lucknow, and M. WILLIS. With a Preface by J. C. WILLIS, Sc.D., M.A. *Third Edition.* **9s. 6d.**

Practical Botany. By FRANCIS CAVERS, D.Sc. *Second Edition.* **5s. 6d.**

Botany for Matriculation. By Dr. CAVERS. **8s. 6d.**

Biology—*continued.*

Senior Botany. By Dr. CAVERS. *Second Edition.* 6s. 6d.

Junior Botany. By Dr. CAVERS. 3s. 6d.

First Course in Plant and Animal Biology. By W. S. FURNEAUX. 3s. 6d.

Plant Biology. By Dr. CAVERS. 6s.

Life Histories of Common Plants. By Dr. CAVERS. 4s. 6d.

Zoology, Text-book of. By H. G. WELLS, B.Sc., and A. M. DAVIES, D.Sc. Revised by J. T. CUNNINGHAM, M.A. *Sixth Edition.* 8s. 6d.

Physiology, A First Course in Human. By G. N. MEACHEN, M.D., B.S. Lond., M.R.C.P., M.R.C.S. 3s. 6d.

Applied Sciences, etc.

Building Construction, A First Course in. By BRYSSON CUNNINGHAM, D.Sc., B.E., F.R.S.E., M.Inst.C.E. *Third Edition.* 4s.

Electrical Engineering, Continuous Current. By W. T. MACCALL, M.Sc., M.I.E.E. *Second Edition.* 15s.

Electrical Engineering, Alternating Current. By W. T. MACCALL, M.Sc., M.I.E.E. 15s.

Technical Electricity. By H. T. DAVIDGE, B.Sc., M.I.E.E., and R. W. HUTCHINSON, M.Sc., A.M.I.E.E. *Fourth Edition.* 12s. 6d.

Engineering Science, A First Course in. By P. J. HALER, M.B.E., M.Sc., A.M.I.Mech.E., A.I.E.E., and A. H. STUART, Ph.D., B.Sc., F.R.A.S. *Second Edition.* 3s. 6d.

Engineering Science, A Second Course in. By P. J. HALER and A. H. STUART. 5s.

Heat Engines, A First Course in. By J. W. HAYWARD, M.Sc., A.M.I.Mech.E. *Second Edition.* 4s.

Worked Problems in Heat and Heat Engines. By Dr. STEWART. *Rewritten and Enlarged.* 1s. 6d.

Hygiene, A First Course in. By R. A. LYSTER, M.D., Ch.B., B.Sc., D.P.H. *Sixth Edition.* 4s.

Hygiene, A Second Course in. By A. E. IKIN, B.Sc., LL.D., and R. A. LYSTER, M.D., D.P.H. *Third Edition.* 5s.